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14. ABSTRACT
The advent of the Internet followed by the transformative diffusion of Web 2.0 has the potential to revolutionize the delivery of clinical training in healthcare in both remote and urban clinical environments [1-4]. This is of significant interest and relevance to the military given the shortage of healthcare providers and the remote locations in which the military has to operate. The objective of this proposal is to design, develop and evaluate a socially relevant knowledge driven collaborative training network. The scope of the project would include geographically distributed clinical teams solving medical decision making problems with the help of Web 3.0 tools that include virtual social networks. During this period we have defined clinical team activities for which the virtual worlds will be used. Focusing on Advanced Cardiac Life Support training, we have developed a virtual world platform to enable training of geographically disparate teams on ACLS training. Coupling haptic devices with the virtual world, we have enabled a multi-sensorial platform for team training. The initial experiment shows the validity of the developed system to address needs of retraining and sets the stage for testing of the developed system.

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Introduction

After developing the initial framework in first year for virtual worlds and developing the underlying architecture, this year our experiment focused on using the system to address a clinical area. We focused on cardiopulmonary resuscitation. Cardiopulmonary arrest (more commonly known as cardiac arrest) is the absence of mechanical activity of heart or, abrupt loss of functionality of heart. According to the American Heart Association, almost 80 percent of cardiac arrests, which occur out of hospital, are witnessed at home by a family member [33]..Approximately 6.4 percent of the patients who have a cardiac arrest ultimately survive [33]. This shows the importance of Advanced Cardiac Life Support (ACLS) skills, which requires a team to perform various tasks within a few minutes of patients' arrival in emergency room. It is a time-constrained, sequential procedure and complex team work that requires proper communication and coordination between the team members in order to save a patient's life. The ACLS team has only five minutes to perform the sequence of actions, both cognitive (eg. decision-making such as which medicine to give, diagnosis of treatment scenario) and psychomotor (eg. CPR), in order to save a patient. It all depends on the performance of the team, not the individuals, during the procedure that they follow to save the patient. If a team member makes a mistake, all good work done by the team will become insignificant, and ultimately the patient can die.

In most fields in which time is the most important factor and which require expertise on cognitive as well as psychomotor skills for better decision-making skills, novices require an expert to disseminate knowledge and skills to them. Theoretical knowledge can be learned in classroom environments whereas procedural skills and communication skills require more practice to perfect. This approach of master-apprenticeship (or apprenticeship in common) model of education has been in existence for a long time, where master performs a procedure and trainees carefully observe the procedures and practice them. From theoretical knowledge to procedural skills to communication skills, this model best fits the requirements. In the case of psychomotor and communication skills, this is more important, because, most of the trainees do not have any idea on what they are going to do during their initial learning phase. However, there is a limitation that at any point of time, a trainer can only train a limited number of trainees [1].

Hamman, Beaubien, and Seiler [34] present the fact that errors in health care are directly related to the failures in the structure and function of the systems. The authors also mention that team training is given less preference than training an individual, although most of the care delivery is performed by teams of people. As mentioned earlier, ACLS is a team-based time-critical activity, so, in order to deliver better care to the patients, we need to understand the importance of team training as well as consider more effective ways to provide training for teams.

What is ACLS?

ACLS refers to certain clinical interventions intended to treat life threatening medical emergencies such as cardiac arrest and/or respiratory failure etc. To master ACLS, it requires extensive medical knowledge, training and practice. Only qualified healthcare providers such as physicians, nurses and paramedics etc. can provide ACLS as it requires several qualified skills such as understanding emergency pharmacology, managing patient's airway and interpreting electrocardiograms.

Life threatening situations as cardiac arrests are announced as a code blue situation. Code Blue is one of the hospital emergency codes that are used to alert several emergency situations in the hospitals worldwide so that the staff is aware and able to react to the situation as fast as possible. Code Blue means that there is a patient who is suffering from a severe life threatening situation and he requires immediate resuscitation (needs ACLS). There is a dedicated team of nurses who specialize in responding to these situations. The team needs to be aware of the situation quickly and act accordingly since the patient needs immediate attention. The delays in response may result in death of the patient.

Once the code team has assembled they have to follow predefined protocols. They have very limited time to react and it is literally a life or death situation. They are bound to make some mistakes under this stress and tension. Our hypothesis is that we can decrease the error rate significantly if we focus on the procedural aspect of their activities.

ACLS: current training approach

Almost all patient-care organizations provide regular ACLS training to facilitate emergency care providers to enhance their ACLS skills. In a typical training session, training team members arrive at the practice room. They initiate the process by assigning roles at first, then divide the tasks according to the roles, and follow the tasks. The team's performance is monitored and evaluated by an evaluator throughout the period. After the session, the evaluator gives a final score based on the team's performance, and later s/he debriefs what happened and what should have been done in the practice room. There might be a brief didactic session on ACLS too. After the debriefing session (and the didactic session), the team will perform another test, and the team is expected to perform better than the previous session. The same evaluator will evaluate the second session as well.

The problem(s)

Although the training system looks promising, there are various issues that are being compromised. The cost associated with overall setup falls on a higher range, and the time taken for training takes about 2 to 3 hours to complete. Much of this time is due to the large amount of orientation needed for training. In the context of learning, the training participants are not guided during the practice session. So, they have to recall what they had learned previously in the didactic session. There are not enough trainers to provide training to the trainees frequently because of which trainees get less time to practice the procedures properly. Apart from these, the ACLS training sessions occur once in every three weeks, which is not enough for practice when we consider the criticality of the ACLS skills.

Learning in virtual worlds

With rapid development of computer storage, memory, processors, and high speed network infrastructure, it is now possible to create a virtual reality based simulations in a networked (distributed) environment that helps users to learn team coordination skills. Computer Supported Cooperative Work (CSCW), in general terms, is considered to be a collaborative work done by users who are located at different sites. Tele medicine, tele-health, tele-conferencing all are examples of CSCW. When CSCW is integrated with the term Virtual Reality (VR), the environment is called as Collaborative Virtual Environments (CVE), or simply “Virtual Worlds”, which provide immersive virtual environment where users can perform various actions, and can also communicate and collaborate with others in the environment. CVEs have been used in various fields like gaming [4], online community building or socializing [4, 5], educational or working environments [6, 7]. CVEs are able to convey the social dynamics like turn taking, cooperation, appraisal, communication to users in a proper manner. In addition to that, users can be assigned different roles like doctor, patient, trainer, trainee etc. Current CVEs also support different media required for communication (text, audio, video), which are very important for group discussions.

How virtual worlds can persuade users to change their behavior and attitude

Because of the features that virtual worlds provide, they have potential to change behavior and/or attitude at different situations and different circumstances. Fogg mentions that there are many reasons that computers can be better persuaders than humans [8]. Some of the important reasons are: computers are more persistent; they provide greater anonymity; they can offer various modalities; computer programs can be re-scaled as per users’ need; and the most important one – “computer can be ubiquitous”. Virtual worlds provide all these features. They are more persistent; they are able to hide users’ information; various input output methods can be integrated with the virtual worlds; and can be modified as per the requirements. In presence of internet, virtual worlds can be accessed from any part of the world. Hence, we can say that CVEs are an integral part of persuasive framework in various fields like gaming (eg World of Warcraft), communications (eg. virtual shops: Amazon.com, eBay.com etc.), training systems for physical exercise (eg. virtual trainers: TripleBeat, Wii Fit etc). With these abilities, computerized virtual reality based interactive systems have potential to persuade human users in the field of education as well.

Advantage(s) of training in virtual worlds

The most important advantage of use of computer based simulation in the field of education is that it can motivate students to learn and practice in a safe environment [9]. Simulation also enables students to practice different procedures in different contexts and different situations. Chodos et. Al. suggest that virtual world simulations consume less resources and are capable of providing safe and realistic environment to practice [1]. The added persuasion in the computer simulation allows students to learn what the causes are and the effects caused. This persuades students to enhance their skills on role-playing, and changing their attitudes towards different perspectives [8].

Learning in virtual worlds: what is required?

Research on team training in CVEs is still at its infancy. Current applications of CVEs do not consider implementation of time-critical high-performance system. They still lack the integration of cognitive task as well as psycho motor task by providing an interactive platform to users to perform the tasks. There are many team based activities which include sequence of actions and are constrained by time and team-members have to complete their task within the specified time frame maintaining high performance level. Research studies have shown adverse effects of time criticality on performance of users, which also hinders the persuasiveness in the CVEs. In virtual worlds, it is more likely that users will pay less attention while performing time-critical procedure. The lack of verbal interaction, physical cues (like facial expressions, eye movement, movement etc.), and psychological cues (like feelings, humor, preferences etc.) are also major barriers for the implementation of persuasion in the virtual worlds.

Contribution and hypothesis

In this study, we try to address the issue of team training in time critical scenario (ACLS in our case) and also the learning behavior of participants in different scenarios: when the participants are provided with persuasive elements and when they are not. We then discuss whether the participants can transfer the learned skills to the training room at a hospital. Finally, we also see whether the participants can retain the skills in the virtual world. We also discuss the novel approach of integration of haptic device to the virtual world for time critical activities that requires psychomotor skills. After the study, we predict that:
Hypothesis 1#: Virtual worlds are significantly effective in delivering team training.
Hypothesis 2#: Participants will retain the skills over a longer period of time.

Objectives

CVEs have huge potential to provide training to many users in a virtual environment simultaneously. Our main goal of this study is to design and develop an interactive collaborative team training simulator that persuades users to perform a sequence of cognitive as well as psychomotor actions in time-constrained environment.
The study also focuses on the following important issues:

- Evaluate the validity of virtual worlds in delivering team training and retention over a long period of time.
- Monitor and record activities (and hence performance) of users while performing a collaborative task.
- Create an online result sheet, which can be accessed from anywhere to view own performance. (The security feature of the performance sheet can be customized: teams can view only their results; whereas a supervisor can view all results).

Body

Background. The project commenced in October 2008. From a financial perspective, many original quotes for equipment were no longer valid due to significant price increases of the equipment since the original proposal was submitted. This limited the ability to complete the proposed project for developing physical telemedicine connections across the western region of Banner. More importantly, the project did not have a clinical champion as the Principle Investigator and that would have been a major roadblock in accomplishing the goals of collaborative telemedicine. These factors were recognized within the first three months of the project, and at which stage TATRC was informed about the difficulties that had arisen. Arizona State University (ASU) continued to develop the web 2.0 backbone for the project, but the project was halted at that point. At this stage, we contacted TATRC to better define a new project within the lines of military relevance and of importance to our organization.

Banner Health presented a new plan to TATRC and it was approved on June 12, 2009. The actual project started in July 2009. Since the project start we have made some rapid achievements in laying the foundation of the virtual world.

To lay the foundations of our work, we will present the related work and then highlight our conceptual framework

2. Related Work

We sub categorize this section into three parts: Team Training, Training in Virtual Worlds, and Persuasive Technologies.

2.1. Team Training

Any coordinated effort, performed by a number of people in a group is termed as team work. Communication, coordination, cohesion etc. are typical characteristics of a team. All the team members should possess these skills in order to carry out assigned task. Team training is very crucial if well coordinated team work is required.

Today, almost every single case of care delivery in hospitals or outside hospitals involves a team of healthcare professionals yet it has been observed that more often than not, individual training is given more importance in real life [27]. There are various reasons behind this fact such as it is often hard to set up training sessions according to each individual's schedule, health care professional trainees are from disparate locations etc. These healthcare training programs need to increase training experience of working in interdisciplinary teams for every individual caregiver. Hamman W et al demonstrated that identifying and focusing on team critical tasks and events prior to and during the training respectively, actually lead to significant performance improvement in teamwork skills [27].

Implicit coordination is one of the characteristics of high performance teams, where communication overhead is very less because the participants have access to the information without asking explicitly [28]. Communication overhead is typically the cost of communication/interaction measured in time, internet bandwidth etc [29]. Another aspect that vitally affects an individual's ability to work in a team is shared mental models. As team members engage in a group activity, they tend to have similar thoughts/ideas in order to accomplish the task which ultimately results in less communication across the team [30]. These aspects are essentially a part of team dynamics which is important to be considered in a design phase of any experimental groupware activity.

Score is an important factor in motivating participation. Toups Z et al observed that if points are given based on team efforts, participants try harder to work as a team and accomplish the task in a well coordinated and organized team effort [31].

Advanced Cardiac Life Support (ACLS) is a time-critical activity carried out by a dedicated high performance team. Training for such high performance teams is in real life scenarios is neither possible nor advisable since it is generally a matter of someone's life. Simulation training is one of the best solutions available. According to Wayne et al, simulator training has shown significant performance improvement in a team of physicians while performing ACLS [32].

2.2. Training in Virtual Worlds

Based on their purpose, Collaborative Virtual Environments (CVEs) or virtual worlds can be categorized into one of the following types: gaming, socializing or online community building, and educational or working environments [19]. [19, 20] outline the various factors that need to be present in a virtual world to be suitable for educational purpose. The authors compare various CVEs and come to the conclusion that selection of a particular CVE depends on the purpose of the training system. Below, we will briefly explain the research on CVEs that focus on healthcare and emergency training.

Wiecha et al explored the potential of a virtual world, Second Life (SL), as a delivering tool for continuing medical education (CME) [10]. In their study, participants had to select and adjust insulin level for patients with type 2 diabetes. For that purpose, participants had to listen to an instructional 40-minute insulin therapy talk. Two mock patients are also included in the study so that the participants can interact with the patients, and discuss within themselves. A questionnaire was provided to the participants before and after the talk session. The study shows that virtual world is very helpful for CME education by showing significant increase in the score after the talk than prior to it.

Losh [15] lists several research work done by the Interactive Media Laboratory at Dartmouth Medical School based on virtual environments. Virtual Clinic is one of such work where a virtual clinic is designed by following the master floor plan. The main objective of this work is to allow learners learn about social behavior and various procedures in clinical environments. The Virtual Terrorism Response Academy (VRTA) is a simulation based game to train users on how to act during crisis. The simulation focuses on providing rescue efforts when hazardous materials are involved. Before starting the game, users have to choose and assign themselves a 'role'. Based on the role, which can be a fireman, emergency medical technician etc, training is provided in didactic learning space. Quizzes and interactive videos are also included in order to engage the users. In an experimental session, a scenario is provided to the users and the main objective of the users is to practice with radiation meters and see how the exposure levels change when nearing hazardous objects.

Similar to VRTA is Play2Train [18]. It is a virtual hospital and town environment which is created by Idaho Bioterrorism Awareness and Preparedness Program (IDAPP). The realistic virtual environment of Play2Train provides various kinds of emergency preparedness videos in virtual classrooms, and also supplements several training exercises to prepare users in case of emergency situations. After the practice sessions, the procedure followed by the students can be debriefed by the instructor to clarify the experiences; an essential part of simulation-based training.

Callaghan et al use Second Life to create a virtual learning environment for engineering education. They demonstrate various interactive simulations that are part of engineering education [12]. Apart from the simulations, a virtual lecture theater is also present in the virtual world which contains interactive mini/main lecture slideshow viewer, media centre for streaming video content and message centers for feedback. As Second Life does not provide SDK, the authors use open source e-learning software SLOODLE that links Second Life with a course management tool named Moodle. After demonstration of the simulations, the participants are asked questions: if they answer it incorrectly, they have to run the simulation again and answer the questions correctly. However, the study lacks the assessment and the evaluation of participants and they mention that these shortcomings will be their main focus in the future. Boulos, Hetherington, and Wheeler [16] describe the potential use of Second Life in medical and health education. The authors provide two scenarios – 'Virtual Neurological Education Centre' (VNEC,(http://www.vnec.co.uk) and 'HealthInfo Island' (http://infoisland.org/health_info). The former demonstrates a scenario where users are exposed to most common neurological disability symptoms. Apart from the symptoms, they are also provided with related information, events, and facilities in the Second Life. The latter involves providing training programs for virtual communities. It also intends to provide support to Second Life residents by providing them opportunities to participate in different medical groups dealing with stroke support, cerebral palsy etc.

The research study performed by Chodos et al [1] focuses on the development of a research-based virtual environment to enhance communication skills for health science education. They provide two case studies. The first one is the development of EMT/ER training simulation, which delivers an environment to train EMT/ER personnel on taking care of accident victim before taking him to a hospital. This case also focuses on exchange of patient information between EMT and ER personnel. The second case is designed to teach various competencies to students like rehabilitation medicine, nutrition, physical education etc. For the second case, the authors design a simulation in order to increase communication between the students to develop a home-care plan for elderly patient. Based on the case studies, they discuss the expectations of students towards virtual world based learning and the quality of learning.

There are several other projects that focus on virtual healthcare system. Second Health is one of such projects where users can learn about how to use medical devices in hospital settings [12]. An interactive clinical scenario is provided to learn medical device training in simulated clinical environment. The participants are provided with both formative and summative feedback during the training session. However, the system does not provide clinical-skills training component in a collaborative environment where multiple users make a team and perform a collaborative task. Similarly, the Ann Myers Medical Centre [13] and the nursing training program from Duke University [14] provide meeting places for medical educators and students, where instructors can present lectures and present educational materials, and students can interact with each other.

2.3. Persuasive Technologies

Various researchers have worked on finding appropriate way to persuade users to perform various activities. Fogg [8] defines persuasive technologies as “interactive computing systems designed to change people’s attitudes and behaviors”. He lists various persuasive technology tools (terminologies) that can be an integral part of any system in order to encourage/discourage users to perform some actions within the system and change their attitude and/or behavior while doing so. In medical training/education, persuasion is one of the most important factors that can affect the performance of trainees/students. Use of meaningful persuasive components (rewards, realism, social presence etc) enhances the learning where as bad design of persuasive components hinders it. In this section, we will mention some of the research work that has been done to encourage users to perform activities within a given system.

Conradi et. al. [17] propose an idea of collaborative learning through problem-based learning (PBL) in Second Life, which they call PREVIEW. Researchers prepared five virtual patient scenarios for learners, which were later delivered to the learners through Second Life platform. The main objective of the study was to find whether computerized simulation based PBL can be more effective than classroom based PBL. To engage students effectively in training the environment provided greater realism, active decision making, and suitable collaboration environment where the participants can interact with each other. The study shows that realism, and suitable interaction environment provided by Second Life engages students effectively in learning.

Consolvo et al look at the design requirements for technology to encourage physical activity in [21]. For this study, they come up with a mobile phone application to encourage users to perform physical activity. The application has three different versions: baseline, personal, and sharing. The sharing version was the most advanced where users not only can see their activity, but also can share their performance to others and view others performance. Based on their study, they describe various factors that motivate users to perform physical activity. Giving proper credit on completion of each task, and providing personal awareness on users’ past performance, and current performance are the basic elements of the system that persuaded users. Another important factor is social interaction. According to the authors, social influence creates social pressure, which motivates users to be the best (or at least not the worst) in the society. TripleBeat [22] is also a similar kind of mobile phone based system that motivate runners to achieve predefined exercise goals using musical feedback as well as competition based persuasion, and real-time personal awareness. The experiment results conclude that the system is “significantly more effective” in helping runners to achieve the goals.
How blogs and podcasts can be helpful tools to provide more sense of community in a group is explained by Firpo et al [23]. The major objective of their study is to change attitude and behavior of a community at School of Information Systems and Technology (SISAT) in order to

foster a sense of community amongst its members. Based on the functional triad explained in [8], the authors conclude that social presence and credibility as the key factors to persuade the members in the community.

Several virtual reality based games have already evolved to motivate users to maintain good health. The following simulation based applications have proved the fact that simulated environments are very effective to change one's attitude and behavior. The Tetrix VR Bike [24] is an environmental simulation that motivates users to work out on this device by exploring the virtual environment. The faster users pedal, the faster will be the exploration. Another simulated environment is Bronkie the Bronchiasaurus [25], which is designed to help kids with asthma to manage their condition. The study showed that the asthmatic children who played the game for at least 30 minutes report increased self-efficacy to take care of their chronic condition. Similarly, HIV Roulette [26] is another simulation to provide immediate insights into sexual behavior. Users can view and select hypothetical character along with gender and behavior. Based on the selection criteria, the system reports whether the specified behavior is likely to cause HIV or any other sexually transmitted diseases.

3. Conceptual Design

The concept design of the system is shown in Figure 3.1. The main objective of this system is to allow users to access the system from virtually anywhere (in presence of internet connectivity). The figure displays real world and virtual world sites. Although the team members are in the same virtual world location, they actually are logged in from different locations in the real world. The person who is responsible for doing CPR has access to the haptic device.

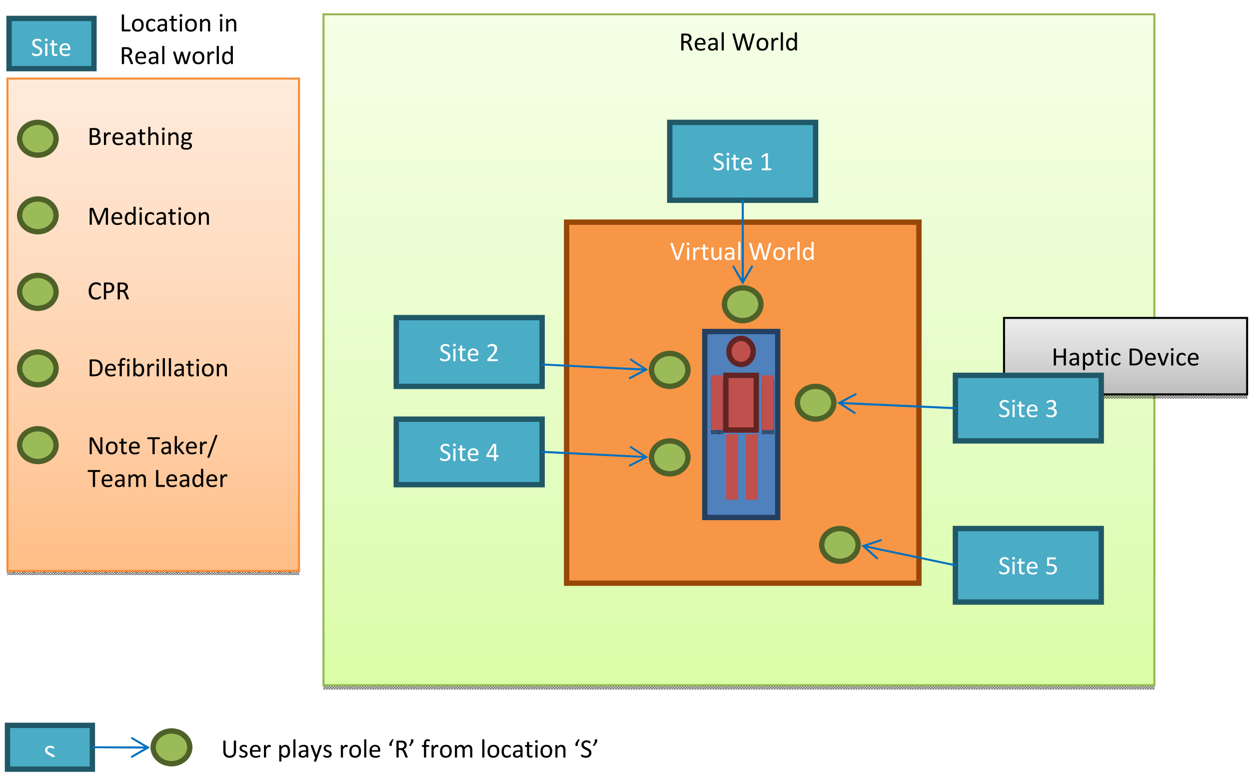

Figure 3.1. Concept Design

3.1 Design Components

Collaborative Virtual Environment: The CVE module controls all the visual aspects of the simulator. We choose Active World as our CVE in order to design and implement our virtual hospital in the world. Users can log in to the Active World using their credentials. After logging into the system, users can navigate the world using their own avatars. Active World allows up to 30 users to login simultaneously, which provides us a platform to perform collaborative work. The users can interact with each other through text messages and can also see each other's actions within the virtual environment. Active World also manages the visual instructions that need to be provided to an "active user". An "active user" is the one who has access to the haptic device. Apart from the instructions, feedback on the user's performance is also provided through the Active World. The main components of the Active World that we use for this research are mentioned below:

- Avatars:
  Avatars are the representation of real people in the virtual environment. Active world provides customizable avatar list. In our research, we use our own avatar, which can perform chest compression animation sequence.
- Objects:
  In the Active World, most of the things, that are not avatars, are objects. In our virtual world, hospitals, patients, visual cues, instructions, buttons are all objects. Different kind of action sequences can be applied on the objects. Actions can be showing/hiding objects, moving objects, etc.
- Animations:
  Animations are parts of action sequences. Apart from showing/hiding and moving objects, Active World can also perform animations, i.e., we can specify separate action sequences at the beginning and the end of the animation sequence.

Haptic module

The haptic module mainly comprises the controlling of haptic device and sending messages from the haptic module to the AW. The haptic device was integrated to the AW to simulate CPR action in the CVE. Novint Falcon is preferred to be used in our study because it is cost effective and it is easier to setup during experimental sessions. When a participant simulates performing CPR action on the haptic device, it triggers an event in the AW. The event that gets triggered is the "CPR gesture" in the AW which is an animation sequence of avatar performing CPR action. The main idea of using the haptic device is to give the perception of performing CPR action in real world. Haptic rendering in this module is the simplest one. Spring force is applied when the handle of the haptic device is pushed towards Y-axis. As the force resolution of the Novint Falcon haptic device is ------ only, we cannot render high force feedbacks. This would affect the performance while performing CPR as the surface would feel soft. To simulate harder surface, we place a real spring just below the handle of the device so as to render harder force when the handle of the haptic device is pushed in. As we are concerned only with the calculation of the distance of the haptic joystick from the original position to the end position, this is a simple but an effective way to increase the force feedback maintaining consistency of the haptic loop.

Voice module

The idea of integrating voice module in our virtual training system is to provide more realistic team-work and team-coordination while performing a virtual procedure. Not only the realism, we also needed a tool for making calls to the whole team (making conference call) throughout the procedure. Based on the popularity and cost-effectiveness, we prefer Skype to other software that provides computer-to-computer conference calls for free.

3.2 System Design

Figure 3.2 shows the system design that integrates different components of the system. It also visualizes the information flow from one module to others. As we mention earlier, the haptic feedback is local only; the only person who can feel the force feedback is the one who is performing CPR on haptic device. When the participant starts performing CPR, it triggers the CPR animation sequence in the AW, which is visible to all the participants who are logged in to the system at that moment. Apart from animation sequences, the system also provides visual cues on what actions the participant(s) have to do next, such as giving medicine, putting oxygen bag etc. Other visual feedback components, such as scores, summary sheets, etc are also present in the system. Audio components are also made available in order to provide realism to the virtual environment.

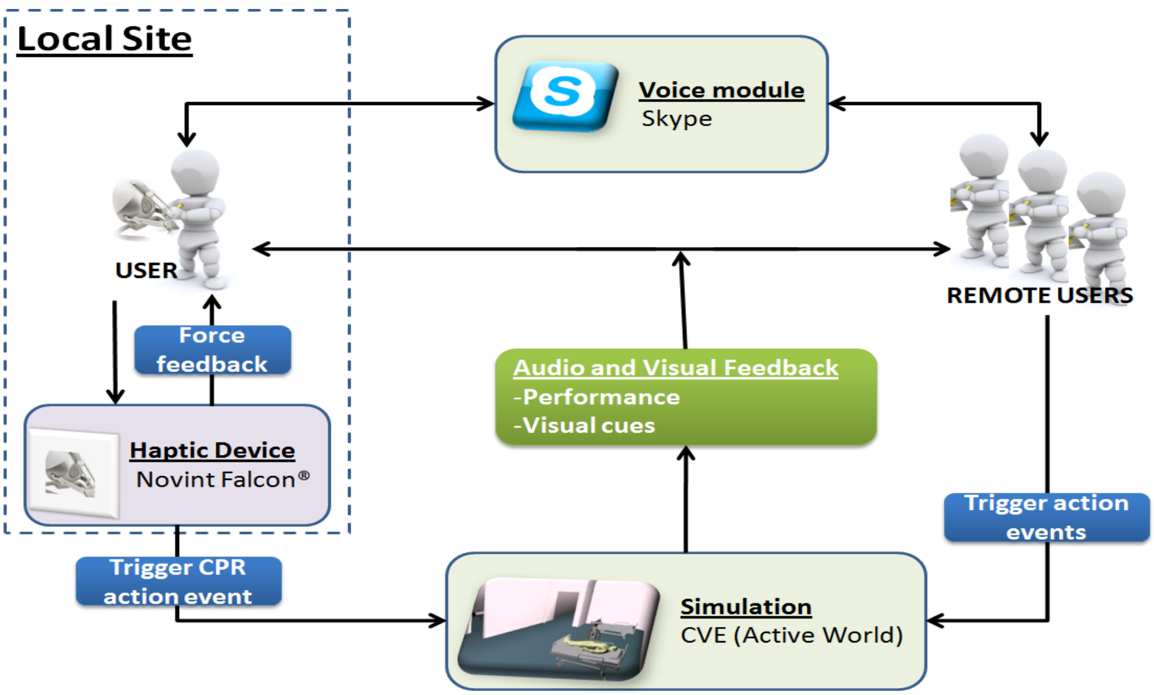

Figure 3.2. System Design

The users can make voice calls to each other using Skype (free computer-to-computer calling). The integration of Skype with the system has two major benefits. The first one is that it provides realistic team coordination during the virtual procedure where they have to frequently ask questions. The second one is that we can record the conversation between the team members and evaluate them later because the conversation between the team members is one of the major factors that affect the team performance.

4. Methodology:

One of the several required skills that an ACLS team member should possess is the knowledge of algorithms. Each team member's knowledge should be evaluated on these algorithms, decisions regarding the patient care, leadership skills etc.

Every ACLS effort must have an assembled team and a designated leader who assumes the responsibility of overseeing the actions of the team. As it is rightly said, "Too many cooks spoil the broth", if there is more than one person making decisions regarding patient care, it may result in total chaos. The team leader is supposed to direct each team member and oversee whether they are following his commands correctly. In resuscitation effort, some tasks can be managed by personnel underwent only Basic Life Support and others require an advanced training.

A resuscitation effort typically requires coordination of four critical tasks:

A – Maintain the Airway

B – Breathing for the patient

C – Begin compressions – if no pulse

D – Defibrillate if required

If a code team consists of 5 individuals, each one of them is supposed to assume one of these critical tasks and the team leader oversees their actions. If the team members haven't assumed these roles then the team leader should quickly assign them these roles as they assemble.

Team Leader

Team leader has important responsibilities; some of them are listed below

- Assesses the patient.
- Ensures that each team member is performing assigned responsibilities correctly and safely.
- Ensures proper interaction and communication between team members.
- Ensures that defibrillation occurs on time with adequate safety.
- Ensures safety of each team member when defibrillation occurs.
- Decides when to terminate resuscitation efforts in agreement with team members.

Airway Management

Some responsibilities of a person who is designated to manage airway are listed below:

- Perform the head-tilt / chin-lift action so that the patient's mouth in proper position.
- Correctly insert an oral airway.
- Know how to verify placement of an advanced airway.
- Know how to place an advanced airway.

Cardio Pulmonary Resuscitation

Some responsibilities of a person designated to perform CPR are listed below:

- The ACLS team member responsible for Cardio Pulmonary Resuscitation must know how to provide compressions of adequate rate per minute, force, depth and chest recoil.
- The person performing CPR should be replaced by someone else on the team every two minutes.
- Patient should not be left without CPR more than 15 seconds whenever ACLS is in progress.

Electrocardiogram Monitoring and Defibrillation

Some responsibilities of a person designated to perform defibrillation are listed below:

- Operation of Automated External Defibrillator (AED) and manual defibrillator.
- Accurate placement of handheld defibrillation patches and hands free patches.
- The safety precautions while performing defibrillation.
- How to troubleshoot the AEDs or manual defibrillators.

Vascular Access and ACLS Medication

Some responsibilities of a person designated for giving medication are listed as below:

- How to perform intravenous(IV) access.
- Awareness of important IV fluids of choice in a cardiac arrest.
- Awareness about medications to be given according to the ACLS algorithm and identified rhythm.

Resuscitation basics

While the code is in progress, the team leader acts as the single point of authority. He/she needs to take initiative and assign proper roles to the team members. The leader needs to guide the team through various resuscitation algorithms. As a team leader, he/she needs to be open to suggestions and ideas.

During a resuscitation effort, two utmost priorities are cardiopulmonary resuscitation and, if a shockable rhythm is present, defibrillation. Advanced airway, vascular access and medication are secondary. The next steps should be taken according to the rhythm present on the monitor. For example, if the monitor does not show any electrical activity and the patient is in cardiac arrest then the situation is identified as asystole. If the monitor shows normal sinus rhythm and there is no central pulse present then it is identified as pulseless electrical activity (PEA). If the monitor shows VTach/VFib, urgent defibrillation is highly recommended. If there is any delay in getting defibrillator ready, CPR should be initiated right away. If the patient is in PEA or Asystole, defibrillation is not recommended. At any point in time, while the ACLS is in progress, if patient's rhythm changes then the ACLS procedure should be changed according to the new algorithm.

When the patient is about to be defibrillated, everyone should be notified to be clear off the patient. Negligence in these activities may result in severe consequences. Once the shock is delivered, the chest compressions and oxygen should be resumed. Pulse checks should take place periodically and emergency care should be continued according to the appropriate algorithm.

Algorithms

There can be five different causes of pulseless arrest / cardiac arrest namely,

1. Ventricular Fibrillation
2. Ventricular Tachycardia
3. Sinus Bradycardia
4. Pulseless Electrical Activity (PEA)
5. Asystole

The algorithms has a main fork, the rhythm on the monitor is classified as shockable / not shockable. We have chosen two algorithms namely

1. Ventricular Fibrillation
2. Pulseless Electrical Activity (PEA)

   from each of these two classes.

The experiment takes place in the Virtual World where provisions are made so that the participants can login from remote locations. For data collections purposes, all the participants will be present at one central site. Their goal will be to diagnose a patient who is having a cardiac arrest in a collaborative effort. There are two modes namely

1. Training Mode
2. Testing Mode

In the training mode the participants are guided through the patient treatment scenario by providing instructions. In the testing mode, participants are supposed to perform the required actions in a team to save to patient. In both modes, their interaction, different gestures/actions, communication etc. is monitored and recorded in the database. Participants are presented with different persuasive elements throughout the experiment. For example, They are given points for every correct action or decision, at the end of the experiment they are presented with a summary screen and with an animated character of a physician expressing his feedback. If they pass the test, the physician is happy. If they fail he is sad.

Along with summary screen, they are given a link to web based evaluation sheet which details their performance on the test / experiment. The participants can only view their own evaluation sheets. The PI has access to all evaluations/reports. These reports will be analyzed to reach conclusions. Below are some screenshots from the virtual environment.

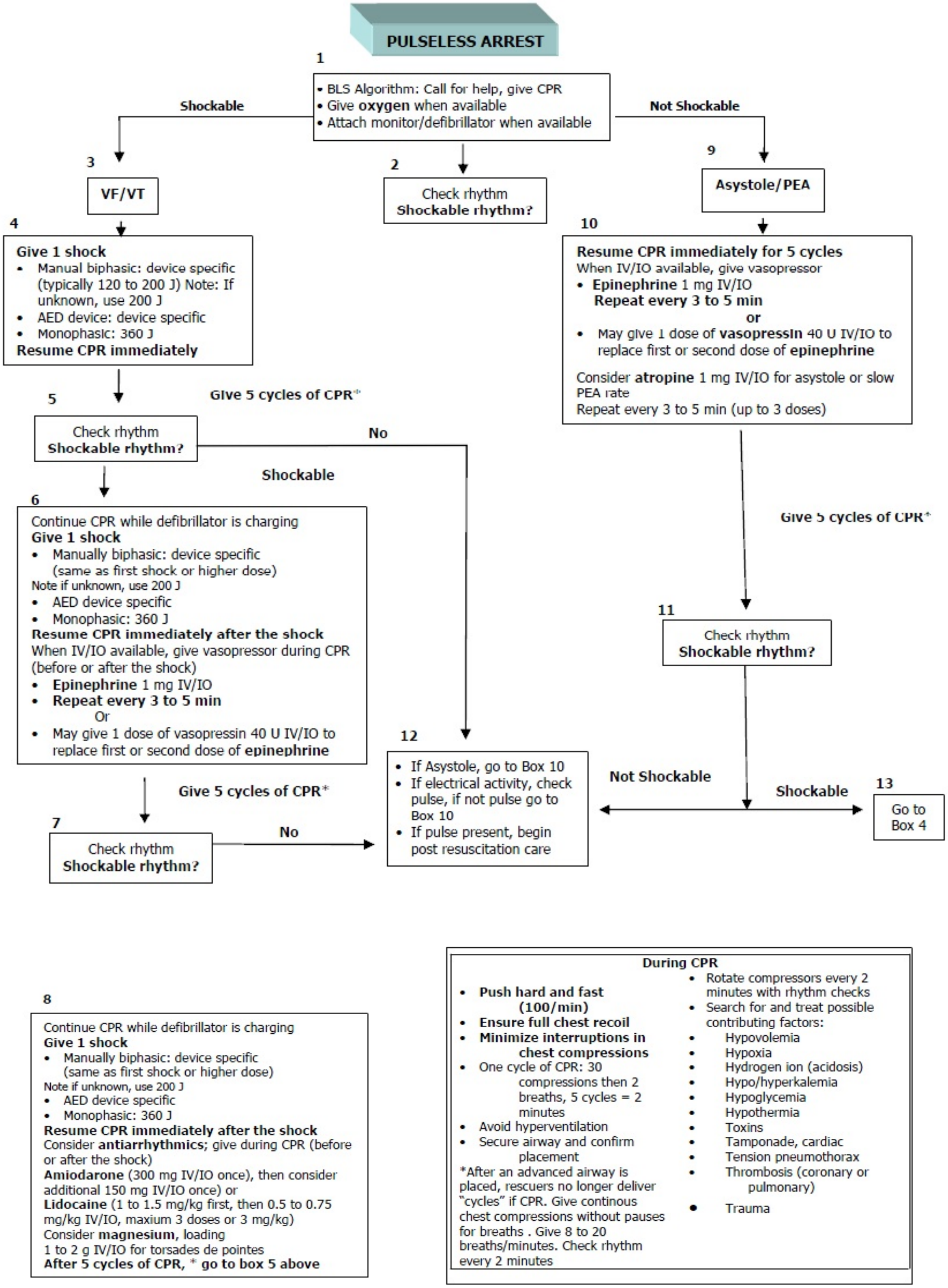

Figure 3.3. Flow chart of ACLS procedure

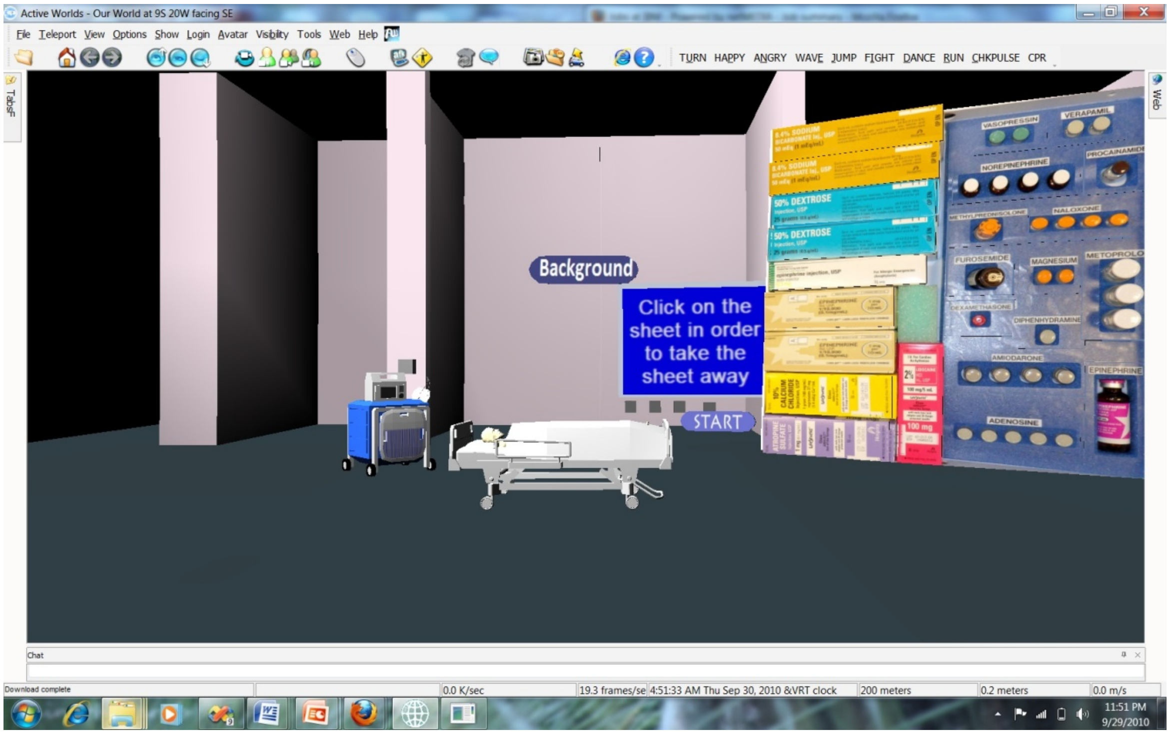

Figure 3.4. Beginning of an experiment (Training Mode)

Figure 3.5. User is instructed to start CPR

Figure 3.6. User has to choose the probable cause of the patient situation

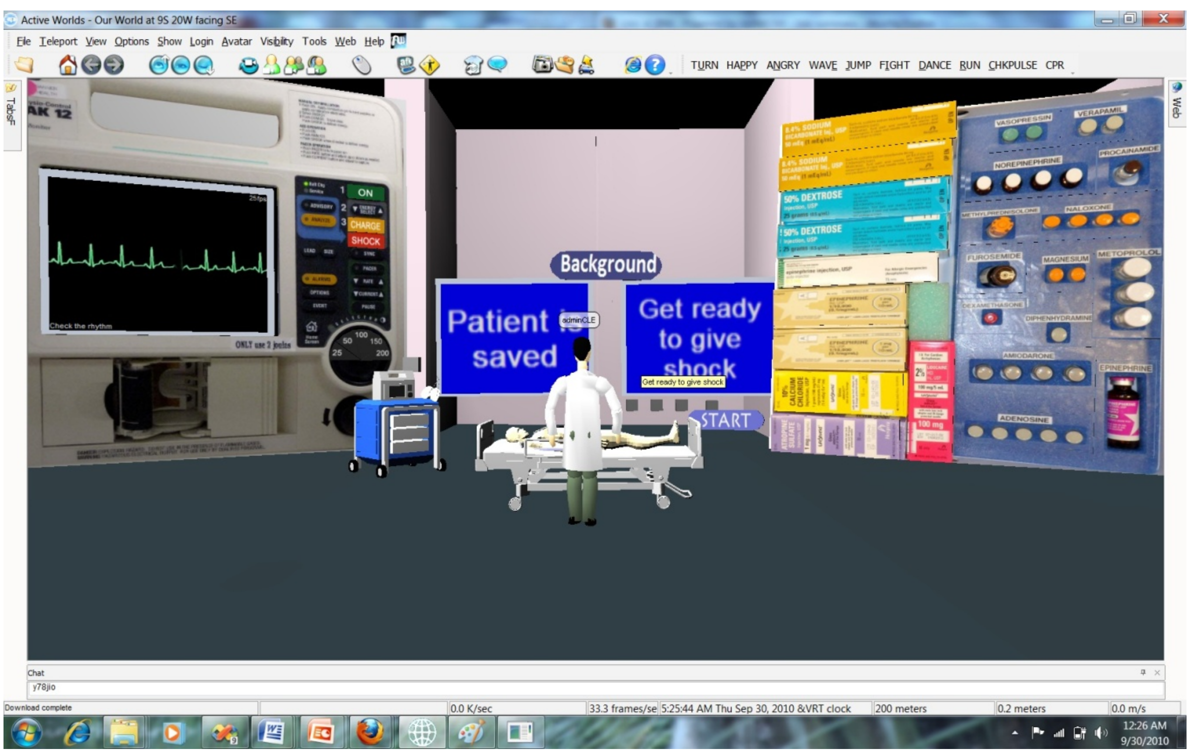

Figure 3.7. Patient is saved when the user performs all necessary actions

5. Persuasive Framework

Realistic models, environment, and presence of others provide better persuasion that motivates users to perform task in virtual environments. We have added real sounds and noise that can be heard in hospital environment in real world (downloaded from website link) to add the realism in the virtual environment. We have also included visual effects such as information boards, animation sequences, and pop-up scores which will allow users to know what they have to do, what they are doing, and how they are doing. Presence of others will also affect the performance of individuals. In our virtual learning environment, more than 5 users are logged in simultaneously. That will make users feel that they are under surveillance in the virtual world and that will eventually motivate users to perform to their best during procedures. The inclusion of voice module will also provide a platform to communicate with each other. Participants can ask questions to each other if they are in confusion. The voice module enhances the team coordination.

The different types of persuasive technology tools (defined by Fogg), which we are using in our system is explained below:

Tunneling

It is a process in which users are "tunneled through" a procedure. Users are informed to perform task 1 (step 1) and then guide them to the subsequent steps until the goal is obtained. Our system also follows this mechanism. When the participants reach the virtual ACLS training room and start doing the procedure in the training mode, they are provided with information regarding the last activity as well as what are they supposed to do next. Figure 3.5 shows screenshot of the system when no pulse is detected and the board is placed below the patient. It also displays what is the next step to be followed (CPR in this cas). Likewise, the system will guide the participants until they obtain their goal, i.e. save patient.

Tailoring

Tailoring helps in two ways: first, they reduce the information based on a given context so that the information wouldn't be overwhelming to the users; second, the users need not memorize all the steps, they can easily recall what they know, if they are shown the options. In our system, there are various checkpoints where users have to decide which choice would be the best one to achieve their goal. At those checkpoints, we provide various options to them. They will make a choice and follow the procedure based on that choice.

Self-monitoring

Another important criterion for persuasive technology is to allow users to monitor themselves. It will require providing them formative feedback on their performance during a procedure. In this system, we provide scores for each and every action that the users perform. If they do not perform the tasks or actions in a correct way, or within the pre-specified timeframe, then they are not provided any points on those actions. This will enable users to monitor their collaborative work at any instant during the procedure.

6. User experience:

6.1. Before starting the training

Participants will be asked to fill a demographic questionnaire before the experiment. Every participant will be given a unique username and every piece of information will be kept confidential and will not be disclosed without user consent. All participants will be assigned laptop computers. They will use their login credentials to enter the virtual environment. Here onwards, their every activity will be monitored and recorded in a secure database.

6.2. During the session

When all the participants in the team assemble, the experiment will begin. Inside the virtual environment, the participants will be asked to navigate around the virtual hospital. After that, they will be taken to the emergency room where they will be asked to diagnose and treat a simulated patient who is having a cardiac arrest. They are expected to do this as a well coordinated team with adequate communication. The participants will be given persuasive motivators as they perform the exercise. At the end of the exercise, they will be presented with a feedback summary screen.

6.3. After the session

They will be given access to their detailed evaluation, where they can verify their performance on the experiment and evaluate themselves against ideal performance.

7. Conclusions

With the system completely designed we are now ready for user testing. An IRB application has been drafted and is ready to be submitted to the DoD for review.

In the meanwhile we have done some initial testing of the system. Specifically we focused on using virtual world based CPR training which is a part of the ACLS training. Kindly see Appendix I for the experimental results which show the validity of our approach. This is a paper ready for review and to be submitted to Journal of Biomedical Informatics.

Another important work in our efforts has been to use Real time location system to drive activities in Virtual World. This work has been accepted for publication in Journal of Biomedical Informatics. See Appendix II for that paper. In the next year, we will link this system with our training system to validate if the training does produce a measurable change in behavior in trauma and critical care settings.

Key Research Accomplishments

1. Development of virtual world which is based on floor plans of training hospital
2. Development of clinical scenario for ACLS in the virtual world
3. Linking haptic devices to virtual world for CPR training.
4. Validation of the CPR training module
5. Development of the Persuasive framework in virtual worlds.
6. Design of experimental framework for validation of the virtual worlds.
7. Cloud based reporting system for evaluation.

Reportable Outcomes

1. Tutorial by Dr Kanav Kahol at American Medical Informatics Association on Virtual worlds.
2. Paper titled "Toward Automated Workflow Analysis and Visualization in Clinical Environments," written by Mithra Vankipuram, Kanav Kahol, Trevor Cohen and Vimla L. Patel accepted for publication in Journal of Biomedical Informatics.
3. Paper titled, "Interactive Haptic Virtual Collaborative Training Simulator to Retain CPR Skills" to be submitted for review in Ambient Systems conference 2011 and extended version in Journal of Biomedical Informatics.

Conclusions

The report summarizes some of the key efforts made in virtual world based training. The underlying technology has been developed and the experimental stage is about to begin. The next phase of human testing is about to commence. We will work with TATRC to ensure goals are met. We will also lay the foundation of evaluation in the field and will work with TATRC to conduct multi-institution trials.

We also plan to link some of our conventional simulators to the cloud and use virtual worlds with simulation training. We believe that would be a major advancement of the science of virtual world. Dr Kahol has also been working on a book on virtual worlds to be published by Biohealthcare Oxford Publications UK.

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Appendices

Appendix I: *Validation of haptic CPR Virtual World system*

Appendix II: *Toward Automated Workflow Analysis and Visualization in Clinical Environments*

Interactive Haptic Virtual Collaborative Training Simulator to Retain CPR Skills

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Abstract. This paper provides a novel approach for training in collaborative environment by integrating collaborative virtual environment (CVE) and haptic joystick. Active World is used as the CVE and Novint Falcon is the preferred haptic device to send force back to the user(s). As our test scenario, we consider CPR skills training simulator for re-training purpose. CPR is not just a compress-and-release procedure - it is a collaborative work and is affected by the performance of each team member. This study also explains the transferability of the CPR skills from this system to the real world case. The data collected 12 participants verify that this simulator provides a healthy improvement on the performance of users who used the simulator before the real CPR on manikins compared to the performance of the users who didn't use it.

Keywords: Collaborative Virtual Environment, CVE, Haptics and CVE, Medical education, Collaborative Haptics Training Simulator, CSCW and Haptics

1 Introduction

Computer Supported Cooperative Work (CSCW) has been a rapidly growing research field after the invention of the Internet. According to Baecker [1], CSCW is an activity, which is performed by groups of collaborating individuals in a computer-assisted environment. He also visualizes CSCW in a form of 2 X 2 matrix of location (local site, different sites) and time (synchronous, asynchronous). Most of the time, CSCW is considered to be a work done by the users located at different sites [2].

Collaborative Virtual Environment (CVE) is generally considered as the combination of CSCW and Virtual Reality (VR) [6]. According to [2], in CVEs, participants share a common virtual environment and are connected to it through a computer network. Participants have their own avatar(s) to represent their identity, location, actions, and gestures. Participants are also able to communicate with each other from within the environment. CVEs are best suited for education as they are capable of providing group discussion (plain text, audio, and/or video), and can also support different media (text, audio, video) to display information about particular topics to the participants. Dickey [5] mentions that a CVE consists of three major components: (a) 3D space illusion; (b) a character to represent real user, called as "avatar"; and (c) an interactive communication environment.

Medical education is, however, slightly different from traditional form of education. Apart from cognitive part of the education, developing psycho-motor skills is also equally important. So far, most of the research on education using CVEs is based on disseminating information to the participants in audio-visual media format. There have been numerous virtual reality based simulators that help the participants learn psycho-motor skills in addition to cognitive skills. However, most of these simulators are stand alone and only one participant can access the system. In real world emergency cases, there is a team and each team member has his/her own task to perform. They switch their role back and forth during the same emergency care session. Clearly, this approach of educating medical professionals or medical students is not suited for medical education because not only are the participants communicating with each other, but are also performing psycho-motor activities at the same time.

A solution for this can be a networked implementation of a haptic based simulator, where each participant can perform certain task(s) in a local system and send the haptic and visual information to a remote system [7]. However, network delay affects the performance of the system as it is a very tedious work to maintain high haptic rate in presence of network delays. This leads to inconsistent haptic feedback and results in system failure most of the time. To ensure stable network based haptic systems, several network based algorithms to control the delay in the network must be implemented. That would be a separate research topic in itself.

In this paper, we attempt to solve the issue of collaborative medical education by providing a novel approach of integrating CVE with haptic joystick. We focus on the chest compression part of the CPR to re-train the users who already know how to perform CPR but haven't practiced it for some time. A participant, who has access to the haptic device, must maintain the rate of 100 compressions per minute while performing CPR on the haptic device. The participant is provided with haptic feedback at real time. Based on his/her performance s/he is given visual feedback in the CVE, so that s/he can improve his/her performance. His/her performance can also be seen by other users who are logged into the system at the same time. This study also intends to check whether the participants retain the CPR skills afterwards.

In traditional CSCW matrix (by Johansen and Baecker), most of the CSCW systems were based on visual mode (texts and graphics). For newer generation of CSCW systems, it is difficult to visualize a system that has a part running on local system and another part running in local as well as remote systems. Hence, we also add a new dimension to the CSCW matrix – "display", to properly visualize the type of CSCW system. By "display", we refer to the output modality of the system. The new CSCW 3D matrix is more intuitive to know about the system that is being represented. The idea of CSCW 3D matrix is picturized in Figure (1).

The paper is organized as follows: we outline related work in Section [*Related Work*]. The overall system design, methodology, and implementation of the simulator is explained in Section [*System Design*]. The experimental design, setup, and participants are described in Section [*Experimental Design*]. The results obtain from the simulator are presented in Section [*Results and Discussion]*. Finally, Section [*Conclusion & Future Work*] concludes the paper.

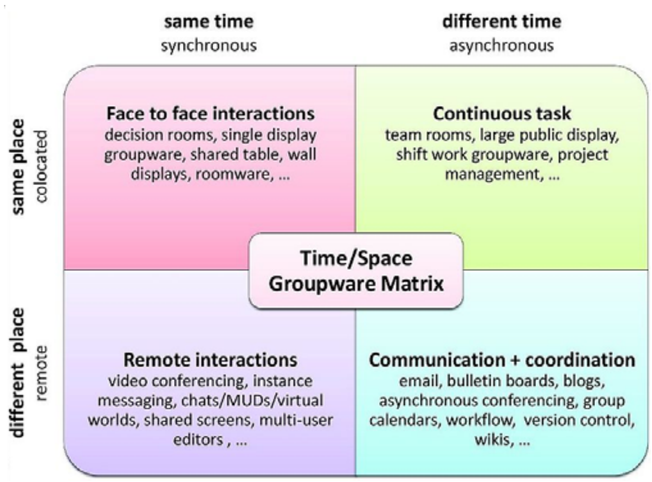
2 Related Work

Several research groups have developed various CVEs in the past. Based on their purpose, they can be categorized into one of the following types: gaming, socializing or online community building, and educational or working environments [12]. However, only a few selected CVEs can be used in the field of collaborative education. [12], [13] outline the functionalities that should be present in a CVE in order to be suitable for educational purpose. The authors take into consideration the systems Croquet (www.opencroquet.org), Worlds (www.worlds.net), Active Worlds (www.activeworlds.com), Second Life (www.secondlife.com), There (www.there.com), Tixeo (www.tixeo.com), I-maginer (www.i-maginer.fr), and Moove (www.moove.com) as test CVEs for collaborative educational virtual environment (CEVE). Each of these CEVEs is tested for the predefined functionalities in order to choose virtual learning platform. Although the authors choose Croquet in [12] and Second Life in [13], they also mention that selecting a particular CVE depends on the purpose of the training system.

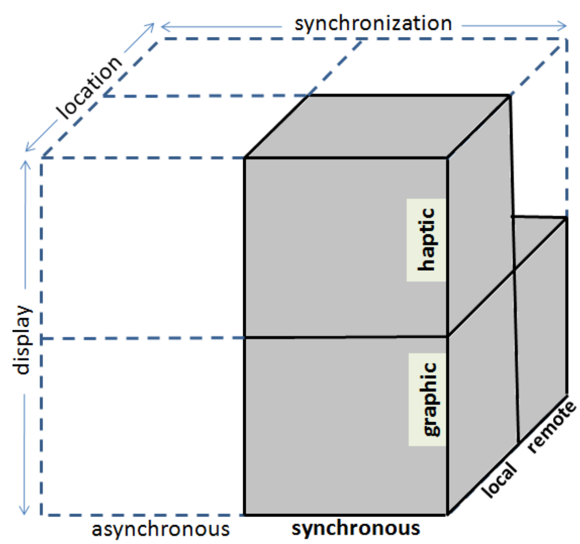
Boulos, Hetherington, and Wheeler [3] describe the potential use of Second Life in medical and health education. They provide two scenarios – 'HealthInfo Island' (http://infoisland.org/health_info) and 'Virtual Neurological Education Centre' (VNEC, http://www.vnec.co.uk). The former involves providing training programs for virtual communities. It also intends to provide support to Second Life residents by providing them opportunities to participate in different medical groups dealing with stroke support, cerebral palsy etc. The latter demonstrates a CVE where users are exposed to most common neurological disability symptoms. Apart from the symptoms, they are also provided with related information, events, and facilities in the Second Life. Conradi et. al. [4] propose an idea of collaborative learning through problem-based learning in Second Life. Researchers prepared five virtual patient scenarios for learners, which were later delivered to the learners through Second Life platform. They also conclude that the CVE engages students effectively in training by providing greater realism, active decision making, and suitable collaboration environment.

The evolution of haptic devices has provided immense opportunities for researchers to develop haptics based virtual medical training simulators. The research, in return, could create a new way of training medical students and/or practitioners. Cheaper haptic devices are available in the market these days, which makes virtual medical training even simpler and easier. Research projects like [8] for needle based procedure, [9] for open surgery, [11] for minimally invasive surgery are only a few of those haptic based medical training simulators that gave medical education a new dimension.

Pascale, Mulatto, and Prattichizzo [10] proposed and implemented a new idea of using haptic device in a CVE. The idea behind the research was to help blind people to navigate around Second Life with the help of joystick. They used Phanom 3DOF haptic device for haptic rendering. Whenever the user encountered an obstacle, the system renders some force to the user through the haptic device.



a) CSCW matrix: idea by Johansen and used by Baecker (source wiki)



b) Our system model (highlighted grey) with “display” axis.

Fig. 1. a) Conventional CSCW matrix; **b**) new CSCW 3D matrix.

3 System Design

This section is divided into three sub-sections: Design Components, Methodology, and Implementation.

3.1 Design Components

Collaborative Virtual Environment (CVE): The CVE module controls all the visual aspects of the simulator. We choose Active World as our CVE in order to design and implement our virtual hospital in the world. Users can log in to the Active World using their credentials. After logging into the system, users can navigate the world using their own avatars. Active World allows upto 30 users to login simultaneously, which provides us a platform to perform collaborative work. The users can interact with each other through text messages and can also see each other's actions within the virtual environment. Active World also manages the visual instructions that need to be provided to an "active user". An "active user" is the one who has access to the haptic device. Apart from the instructions, feedback on the user's performance is also provided through the Active World. The main components of the Active World that we use for this research are mentioned below:

- Avatars:
  Avatars are the representation of real people in the virtual environment. Active world provides customizable avatar list. In our research, we use our own avatar, which can perform chest compression animation sequence.
- Objects:
  In the Active World, most of the things, that are not avatars, are objects. In our virtual world, hospitals, patients, visual cues, instructions, buttons are all objects. Different kind of action sequences can be applied on the objects. Actions can be showing/hiding objects, moving objects, etc.
- Animations:
  Animations are parts of action sequences. Apart from showing/hiding and moving objects, Active World can also perform animations, i.e., we can specify separate action sequences at the beginning and the end of the animation sequence.

Haptic module: The haptic module mainly comprises the controlling of haptic device and sending messages from the haptic module to the Active World. A user, "active user", has access to the haptic device, in the real world, and can perform CPR on the material mounted on top of the haptic device. While performing compression during CPR, the user gets an appropriate amount of force feedback. Based on his performance, a message is sent to the Active World, and the system provides feedback in the form of visual cues. The purpose of the feedback is to help the user to speed up or slow down the rate of compression and recoil.

Figure (2) shows the overall design of the system. The direction of the line indicates the information flow.

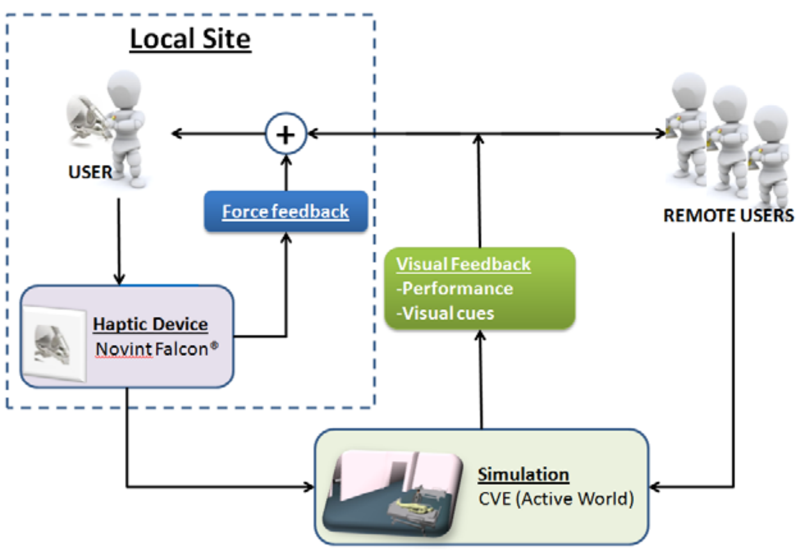


Fig. 2. System Design

3.2 Methodology

This research is part of a mock code simulator in which people work in a collaborative environment. The major objective of this system is to re-train users to perform CPR skills, who already know how to do it, but haven't practiced for some time. Each user's performance is displayed in the CVE (active world). To achieve our goal, we divide the objectives into a set of subtasks. Figure (3) shows the sequence of tasks followed while designing the simulator.

In the figure, the first module calculates force. When participants perform compression, a force is calculated and is applied in the opposite direction. The handle of the haptic joystick moves back to the original position, thus simulating 'recoiling'. Mass-spring model is used for its simplicity and efficiency in our system for force calculation. In the proposed system, the force feedback is independent of the visual feedback – it is not necessary to detect collision between the objects in the CVE. This is very important for a collaborative work like CPR because not all members in a team perform the same task simultaneously; however, the members switch roles every now and then.

After calculating the force, the number and the rate of compressions is calculated. The following algorithm is used to count the number of compressions.

Initialize startPosition at the beginning of the haptic loop,
Initialize countCompression =0; and touchMin, touchMax to false,

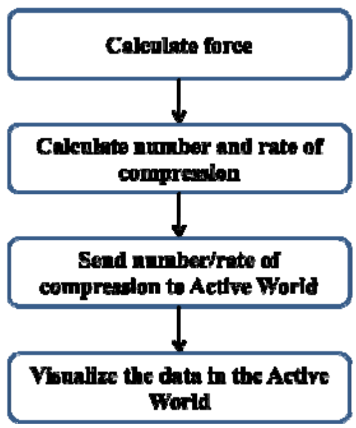


Fig. 3. Tasks flow of the system

Obtain currentPosition, and calculate distance = currentPosition – startPosition,
if distance <= 0, set touchMin = true,
if distance > 1.5 (inch), set touchMax = true,
if both touchMin and touchMax are true, then
    if distance <= 0, then //when it goes back to the original position
        increment countCompression,
        set touchMin = false,
        set touchMax = false,
Repeat.

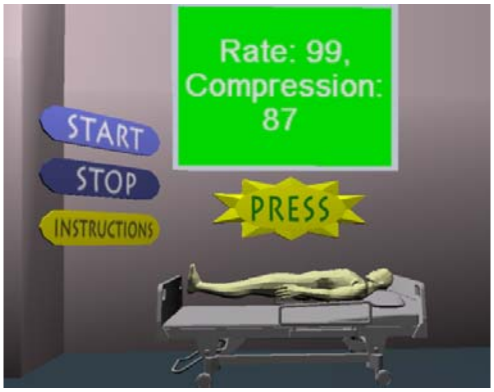
Where, touchMin and touchMax represent the planes when the handle of the haptic joystick is at the initial position and compressed position respectively. The number of compressions and the rate of compressions are then stored in the local computer, which can be used for the validation of the proposed system.

Once the number and the rate of compressions are calculated, callback functions (aw_object_add, aw_object_change) are used, event handlers and attributes (AW_OBJECT_DESCRIPTION, AW_OBJECT_ACTIN) provided by Active World SDK are used to visualize the data in the CVE. These data can be seen by all the users who are available at the virtual training location. The output(s) of the system is shown in Figure (4).

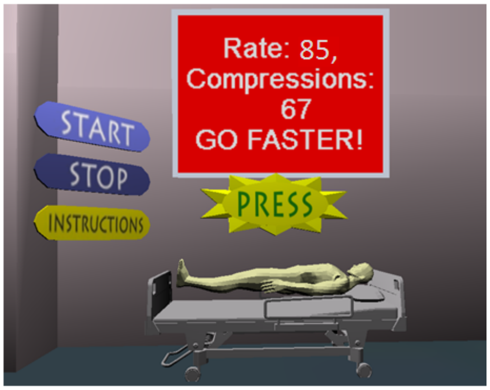
3.3 Implementation

The proposed system follows a distributed architecture. The CVE acts as a server to disseminate information to all users, and runs at a remote site. As discussed earlier, there are many CVEs available; however, Active Worlds is best suited for our requirements. Active World provides its own SDK that helps to communicate and interact with the Active World system from native C/C++ language. Messages can be sent from the local computer to the Active World server following the protocol mentioned in the SDK. The SDK also helps to add, remove, and/or modify objects in the world in the real time.

For the haptic rendering part, we used Novint Falcon haptic. Novint Inc. provides HDAL haptic API to communicate with the Falcon haptic device. The API provides different control mechanisms to control the position of the device and the force being rendered to the user. The HDAL API is available in C/C++.



a) Green board for correct compression-rate.



b) Red board for lower compression-rate.

Fig. 4. Screenshots from the system

4 Experimental Design

Each participant has to perform 3 CPR trials. In the first trial, the participants have to perform CPR without any feedback. They have to maintain the rate of 100 compressions per minute. The second trial provides visual cues and feedback. Participants have to synchronize their rhythm of compression with the visual cues provided on the screen. A 'Press' button is used as a visual cue and it becomes visible and invisible maintaining the rate of 100 per minute. Participants have to perform compression whenever the button appears on the screen, and recoil when it disappears. In addition to the visual instructions, the participants are given feedback on their performance. They are shown their compression-rate, number of compressions and a message (if needed). If their compression-rate is less than 90, then the message “Go Faster!” is displayed, and the participants must increase the rate of compressions. Similarly, when the compression-rate is more than 110 “Go Slower!” message is displayed. These two messages are shown in red background, representing that they are deviant to the actual rate. If their performance is between 97 and 103 compressions per minute, the current compression-rate and the number of compressions is shown on a green background. The third trial is similar to the first one; no visual cues and feedback are provided.

For each trial, the number of compressions, time taken for each compressions (in seconds), and the rate of compression is stored. Our hypothesis is that participants perform better when they are provided feedback (second trial) than when they are not (first trial).

Experiment Setup: 12 participants (3 female, 9 male) participated in the experiment. All participants had basic idea about CPR skills and had already performed CPR before. All of them already knew that they had to maintain the rate of 100 compressions per minute. However, they haven’t performed it for 2 months. Only 5 participants had experience on using the haptic device before the study, all others were using the haptic device for the first time.

Before the trials, each participant was explained about the system, the experimental design, and what they had to do in the experiment. Each participant was provided a minute to get used to with the simulator. When they were ready, the first trial was performed. An interval of approximately 0.5 minute separated the trials. Figure (6) shows how the system was set up for the experiment.

5 Results and Discussion

Figure (6) displays the number of compressions in each trial performed by each participant. The safe range (90-100 compressions per minute) is highlighted in the figure. For each trial, performance metrics of each participant, like number of compression, time, and rate of compression, were recorded. Almost 60% of the participants could not maintain their rate within the range of 90-110 compressions per minute. The outcome shows that people who know about CPR, but do not practice it

Fig. 5. Experiment Setup: CVE shown at the left and haptic device at the right

often, tend to make mistake in maintaining the required compression-rate. The compression-rate varied from 76 to 126 per minute.The second trial was performed in
presence of visual cues and performance feedback. All participants were able to maintain the compression-rate between 90 and 110. The range of number of compressions per minute varied from 95 to 104 in the second trial. Participants performed better in the third trial as compared to the first one. All of them were able to maintain the compression between 90 and 100. The compression-rate varied from 90 to 110.

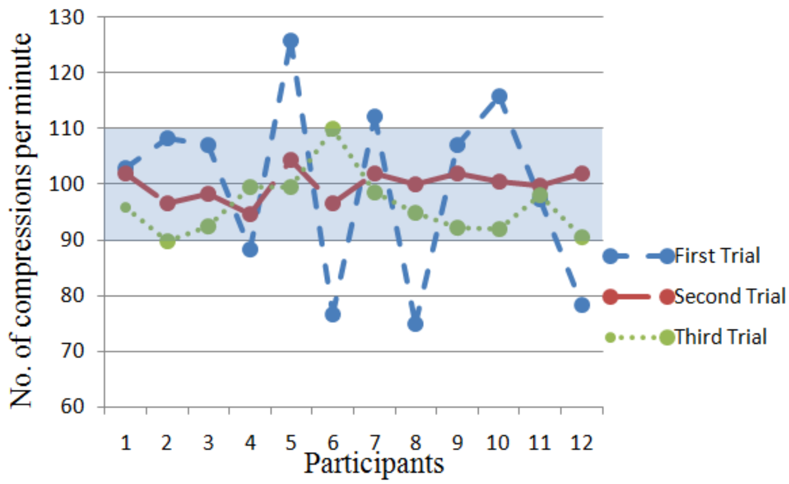


Fig. 6. Performance of 12 participants on each trial (safe-range is highlighted).

We, initially, hypothesized that the participants should maintain the rate between 90 and 110, and providing them the visual cues and feedback would improve their performance. In the visual cues, we displayed their compression-rate, and whether they are going fast or slow, in real time, so that even if they were maintaining the required rate, they can improve to maintain it at 100 compressions per minute. Our hypothesis was verified; when they were provided the cues, they performed much better than when they were not given feedback on their performance. The compression-rate varied from 95 to 104, which was more than that we expected.

In the third trial, we wanted to check whether the participants could retain the skill or not if visual cues are not provided. From the outcome of the experiment, we can say that they could retain the skills. All participants could maintain within the range 90-110.

The important thing to mention here is that the participants did not practice on this simulator for a long period of time. Based on the results, even in that short period of time they spent with the simulator, they could retain the skills. It is possible only because they already knew how to perform CPR. This proves that this simulator helps the people, who already know about CPR skills, to perform better by providing feedback on their performance and to retain the skills.

5 Conclusion and future work

This paper focused mainly on interactive collaborative CPR skills training simulator for the purpose of re-training the users, who already know how to perform CPR but had not practiced for some time. To achieve our main objective, we also presented a novel approach of integrating haptics and CVE by localizing haptic feedback and transfering the positions of the device to the server located at remote site. In the experiment, the participants performed CPR at local site. We performed three trials: first trial without any feedback; second trial with feedback; third trial without feedback. The participants performed a lot better in the second and the third trials than compared to their performance in the first trial. Other users, who were logged into the virtual world during the trials, could also see the performance of each participant.

This opens up different possibilities that we can do with the integration of haptics and CVE. Apart from re-training skilled CPR practitiners, this system can be a part of a virtual mock code training simulator [Sai's paper] where participants perform different tasks during emergency, and they also need to switch tasks in-between. The participants can log in from different locations, and can interactively practice the mock code in the virtual environment.

This can also be used as virtual assessment tool for CPR skills. Participants can log in from a remote site to perform CPR. His/her performance will be stored in a server, where only authorized user can login and evaluate the performance.

Installing haptic devices at different locations and performing a collaborative tasks in CVE will be the future work that we will be focusing on. The future work also includes identify proper depth compressed during CPR.

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Toward Automated Workflow Analysis and Visualization in Clinical Environments

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Abstract

Lapses in patient safety have been linked to unexpected perturbations in clinical workflow. The *effectiveness* of workflow analysis becomes critical to understanding the impact of these perturbations on patient outcome. The typical methods used for workflow analysis, such as ethnographic observations and interviewing, are limited in their ability to capture activities from different perspectives simultaneously. This limitation, coupled with the complexity and dynamic nature of clinical environments makes understanding the nuances of clinical workflow difficult. The methods proposed in this research aim to provide a quantitative means of capturing and analyzing workflow. The approach taken utilizes recordings of motion and location of clinical teams that are gathered using radio identification tags and observations. This data is used to model activities in critical care environments. The detected activities can then be replayed in 3D virtual reality environments for further analysis and training. Using this approach, the proposed system augments existing methods of workflow analysis, allowing for capture of workflow in complex and dynamic environments. The system was tested with a set of 15 simulated clinical activities that when combined represent workflow in Trauma units. A mean recognition rate of 87.5% was obtained in automatically recognizing the activities.

Key Words— clinical workflow; complex systems; medical errors; radio identification; virtual reality; visualization

1 INTRODUCTION

1.1 Workflow and medical error

The health care industry faces a number of challenges and arguably one of the most important ones lies in maintaining high levels of patient safety. A much-cited report released by the Institute of Medicine (IOM) estimates that as many as 98,000 people die each year due to medical errors.[1] Medical errors cause more deaths annually when compared to motor vehicle accidents, breast cancer or even HIV. Consequently, scientists across the world have actively researched the nature of medical errors and the activities that cause the errors. An integral component of this research effort is workflow analysis.

A workflow is a description of a sequence of operations or activities performed by various entities or agents in the system.[2] It provides a description of the context and conditions in which errors occur. Careful analysis of workflow can be employed to model the distribution of cognitive work and the information flow in complex environments. For example, Malhotra et al.[3] utilized ethnographic observations and interview data to analyze the workflow in an intensive care unit. The workflow served in the development of a cognitive model from which details of information flow could be extracted. This type of analysis could lead to the discovery of latent systemic flaws that potentially result in adverse events. In addition, monitoring and assessment of workflow in complex clinical environments can provide clues on the efficacy of patient management. For these reasons, workflows in clinical environments are an important aspect of patient care and safety research.

Recent research has approached the study of social systems such as clinical environments, using scientific theory based on *complex adaptive systems*.[4] A complex adaptive system is defined as a dynamic network of entities acting simultaneously while continuously reacting to each other's actions.[5,6] The control in such systems is often decentralized and highly dispersed. The overall behavior is the result of a large number of decisions made at every instant by individual agents or entities in the environment. In such environments, the inherent complexity of interactions makes capturing and analyzing workflow difficult and often unpredictable. These difficulties can be attributed to a disassociation between the complex nature of the environment and the tools available to analyze the workflow in such environments.

Critical care environments are complex and dynamic and change constantly with stress levels. The changes in staff continually alter team dynamics and the excess of technology and equipment creates unforeseen demands on clinicians. These characteristics allow for the categorization of critical care environments as complex adaptive systems. Consequently, the problems with workflow analysis in complex adaptive systems are applicable to critical care environments as well.

The tools currently used for workflow analysis in clinical environments include methods such as ethnographic observation, shadowing of individual clinicians, surveys and questionnaires.[7] These are *qualitative tools* of analysis. The data collected by these methods can be used to model segments of the workflow centered on a particular individual and their activities.[3] While the workflow generated in this manner captures many aspects of the overall workflow, more often than not, certain key pieces of information may never be captured. For example, observations are gathered from an individual's point of view and may not be adequate to capture multiple activities occurring at an instance of time. Theoretically, by increasing the number of observers in the clinical environment it is possible to capture information about the activities in the environment from several perspectives. However, based on informal interviews conducted with Trauma clinicians, more than two observers are often considered to be disruptive to the clinical workflow. With such constraints imposed on data collection in complex environments, there is a need for an unobtrusive alternative that can augment existing methods of data collection and enable piecing together a more complete workflow, from individual and team perspectives.

1.2 Black-box approach to capturing clinical workflow

An example of complex social system that is similar to a clinical environment is aviation. A critical component of error analysis in aviation is the *black box*. The black box, as a tangible unit refers to devices installed on aircrafts that track both communication within the cockpit of the aircraft as well as performance parameters such as altitude, airspeed and heading. From a conceptual perspective, the black box is a constant monitoring tool that does not interfere with the procedures of aviation and simply monitors parameters pertaining to the flight.

In clinical environments, tools that are conceptually similar to a black box would be able to monitor workflow continuously. In addition, the tools would monitor the workflow without disrupting the activities of entities in the environment. In this paper, we propose a system that utilizes the black-box approach for continuous workflow monitoring and analysis in clinical environments. This system employs radio identification technology (RID) to offer continuous monitoring. RID-enabled tags are portable electronic devices used to uniquely identify entities in an environment. These tags can be used to continuously monitor agents and artifacts in the clinical environment. Basic information about interaction between the entities, such as duration of proximity and location can be recorded. This data, combined with qualitative measures provide an intermediate workflow that can be visualized in three-dimensional (3D), virtual reality (VR) environments. We can combine this system with conventional means of ethnographic observations for high-resolution capture of workflow. The end result is a system that enables the capture and visualization of workflow in complex environments for the purpose of enhanced workflow analysis.

2 BACKGROUND AND RELATED WORK

Methods used to analyze workflow in clinical environments can be one for two types – *qualitative* methods or *quantitative* methods. While qualitative methods involve subjective observations gathered by researchers, quantitative methods typically involve the usage of sensor technology or video recordings to capture data about workflow. The main differences between the data captured using quantitative methods and qualitative methods are as follows:

(i) Using quantitative methods, accurate time-stamped data can be obtained. Human-intensive methods can only produce near-accurate time-stamped observations.

(ii) Qualitative methods of data collection produce relatively low volume, high quality data. On the other hand, quantitative methods produce a high volume of abstract data that in some way indicates underlying workflow.

(iii) Human-intensive qualitative methods best suited for low-intensity situations while automated quantitative methods are optimal for data gathering in high-intensity situations.

The following sections detail the existing qualitative and quantitative methods used to analyze workflow in critical care environments.

2.1 Qualitative methods for workflow analysis

Malhotra and his colleagues analyzed the workflow in the intensive care unit (ICU) in order to understand the process of evolution of error in a critical care setting.[3] Ethnographic observations and interviews are utilized to gather data to model workflow centered on the entities and activities in the environment. The process of gathering observations involves following a key member of the critical care team and recording all of their interactions with other members of the team, patients and equipment. These key players are then interviewed to corroborate the observations collected and to delineate their individual workflows. Using observations and interviews, a collective workflow is reconstructed by combining the individual workflows of each key player. The developed workflow summarizes how ICUs function and where errors are most likely to occur.

Laxmisan and her colleagues utilize ethnographic observations and interviews to analyze the workflow in an emergency department (ED)[8] as well. The workflow is analyzed to study the cognitive demands imposed by the workflow in the context of the work environment. Multi-tasking, interruptions, gaps in information flow and handovers during shift change are some of the aspects of the workflow that are studied in detail.

2.2 Quantitative methods for workflow analysis

Quantitative methods provide some means of gathering information about the activities and whereabouts of entities in an environment. An entity could be a person (nurse, physician, patient etc.) or a machine (such as ultrasound machine). The tracked activities can then be pieced together (similar to integration of observations and interviews) to provide a complete picture of the workflow.

The sensors typically used for entity activity recognition include passive infrared sensors, radio identification tags and pressure sensors. The sensors, depending on their type are utilized to detect various activities that the entity is involved in. A number of systems have been developed for activity recognition and workflow monitoring using different types of sensors. These systems use the various types of sensors in some combination to model key activities of the entity being tracked. In general, these sensors are encased into a physical form representing a tag. These tags can sense different types of information like movement and location through the ensemble of sensors embedded in the physical form.

In the domain of healthcare, tags have been employed for tracking patients, equipment and staff to improve patient care and the efficiency of clinical workflow[9-15]. Fry and Lenert[15] developed a system for location tracking of patients, staff and equipment called MASCAL. The main aim of the system was to aid in streamlining patient care during mass casualty situations. RID tags are used by the system to track the location of key players (clinicians and equipment) in patient care during emergencies. This information is integrated with personnel databases, medical information systems and other applications (such as those that enable registration and triage) in order to centralize the management of resources during critical situations. In addition, MASCAL includes interfaces for centralized management of various entities in the system.

Chen et al.[14], studied the incorporation of RID technology in a clinical setting in non-psychiatric hospitals in Taipei, Taiwan. Tags were used to identify patients, and notify clinicians on the status of patients and patient related information (lab reports, radiology results etc.). Preliminary studies showed that using the RID enabled framework, decreased the length of waiting for patients in intensive care units.

The other technique for activity monitoring is processing of video recordings. Hauptmann et al.[16] describe a system that recognizes activities from videos captured using video processing techniques. The system was developed to recognize activities of daily living (ADL) for patients. Examples of ADL activities include, visiting the washroom, eating, sleeping etc. Cameras placed at key locations within the environment provide video feeds. These video feeds are processed to identify the patients and hence draw conclusions on the possible activities the patients were involved in.

2.3 Limitations of qualitative methods

Qualitative methods are human-intensive, i.e. they require significant amounts of human effort for data gathering and analysis. The dependency of qualitative methods on human effort has certain advantages and disadvantages. The main advantage is that human-intensive methods usually yield data that are of high quality. These data are detailed and descriptive, and potentially insightful inferences can be made using qualitative analyses of these descriptions. The disadvantage however, is that the dependence on people for data gathering and analysis limits the capabilities of these methods to capture important details of the collective workflow in a critical care environment.

Observation gathering is a classical qualitative method for workflow analysis that suffers from its dependence on human effort. It is difficult for individuals to monitor and document all activities that occur at every instant in a dynamic and complex environment. Interviews on the other hand suffer from the poor recall of events on the part of clinicians being interviewed. Facts about events may be altered as the memory of the event changes temporally (post-hoc bias). Other real-time methods of data collection such as audio and video recording systems not only require consent from clinicians to be used to gather workflow data, but also require significant human efforts for processing data collected to retrieve meaningful information. Post-processing of real-time data involves manual analysis of audio and video data in order to detect various workflow events. The real-time data is then manually annotated with the key events that have been detected. This process requires time, effort and sufficient researcher expertise in order to be completed successfully. Such limitations make these methods more suited for workflow analysis in simple, low-activity environments.

2.4 Limitations of quantitative methods

In most quantitative methods, sensors for monitoring activities and locations are placed at pre-defined locations. The rigid infrastructure often makes installation costs prohibitive. In addition, maintenance can be complicated if spatial configurations are altered.

Another issue lies with the modeling approaches employed to track workflow. In all the current systems, the sensor system is employed to determine the location of the entities from which activities are estimated. This system works well if the location identification is reasonably accurate. However, RID systems can often be highly erroneous, resulting in close to 200% errors in location estimates[17]. Location in these systems is determined by geometric triangulation methods that have limited performance in environments with electromagnetic fields. As clinical environments require large amounts of equipment, it is impossible to control for electromagnetic fields. To account for this high rate of error, activities that are covered by the current approaches are macro movement based activities such as entering a room or going from one area of the hospital to another. Current systems are limited in documenting activities that occur in smaller area as the sensors cannot discriminate location in these environments with acceptable accuracy.

Video-based tracking suffers from similar issues. The locations of cameras are fixed. Areas need to be analyzed to ensure that camera cover all parts that need to be monitored. In addition, real-time analysis of videos for entity recognition can suffer from typical video processing problems, such as occlusion of entities by other entities, noise, motion blur, uneven lighting and so on. This, coupled with the requirements of privacy and security, often render video-based capture unusable.

As both qualitative and quantitative methods have advantages and disadvantages, an improved solution for workflow monitoring can be obtained by combining the two types of methods. In this work, workflow monitoring is performed using RID tags in conjunction with ethnographic observations. Unlike infra red tags, RID tags do not require a line of sight with other tags to record information. Hence, we utilize RID tags to gather the quantitative data. Observations gathered complement RID data by providing a detailed description of communication and interaction activities that cannot be captured using the tags. This is the approach taken for the development of the system described in this paper.

3 METHODS

In general, workflow can be described by (a) the underlying cognitive processes that drive decision making, (b) physical movement, and (c) interaction and communication activities. In this work, we present the framework for a workflow analysis system that combines qualitative and quantitative methods of data collection to capture each of these three activities. Figure 1 depicts the types of activities that can be captured using the qualitative and quantitative data gathered. RID tags can provide quantitative information about movement activities, in addition to some basic interaction statistics such as proximity between two or more clinicians and time spent at particular locations. These statistics could be utilized to model the movement patterns of clinicians in the environment and the overall behavior of the clinical team. RID tags, however cannot gather information about specific details of communication between clinicians, or details about the thought processes of clinicians that result in a particular situation. We rely on qualitative observations to provide this information.

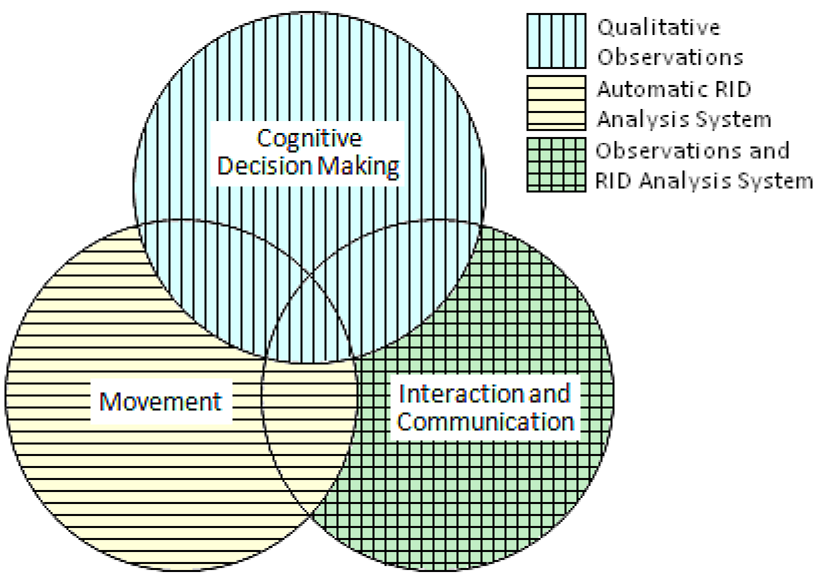

Figure 1. Overview of activities captured and tools utilized

Traditionally qualitative data collection requires observers to focus on both cognitive activities and movement activities. This is in addition to collecting detailed information about the time of activity initiation and the sequence of activities in a workflow. Our system offers the means to offload the task of recognizing movement based activities and a subset of interaction and communication activities to the automatic algorithms that process incoming quantitative data from RID tags and estimate the activity being performed by the team (as depicted in figure 1). Our system can theoretically capture any movement activities that require team members to move at least 8 inches[17]. The communication and interaction activities that show movement patterns of a single entity or a group of entities can be suitably recognized by the developed system.

An example of such an interaction activity would be “patient arriving”. Typically, interactions with two or more entities can be monitored using RID information. When a patient arrives in a trauma room, the team members tend to converge at a trauma pod. This is an interaction and communication activity that can be captured by using movement as a proxy. As a general rule, any interaction and communication activity that is accompanied with measurable movement can be captured by this system and recognized. Following the same logic, any communication or interaction activity that is not accompanied by movement cannot be captured by the automatic analysis system.

In the future we aim to include additional sensors that can give us more detailed information on some of the activities. Incorporation of audio recording would facilitate automated tracking of communication between entities. Further, in order to increase the resolution of the movement activities that can be tracked through our system we aim to use accelerometers. Acceleration measurements could provide information on whether the tagged entity is moving. This would enable the refinement of movement tracking and activity recognition. The presented framework accounts for these future additions to allow for seamless integration.

3.1 Conceptual Framework

In the given framework, we collect two different streams of data,

(a) Qualitative data from observers, and,

(b) Quantitative data gathered from the RID tags.

Both the qualitative data and quantitative data are obtained from standardized sources. While time-stamped quantitative data is retrieved from the RID tags, observations are generated by observers using an activity tracking software tool depicted in Figure 2.

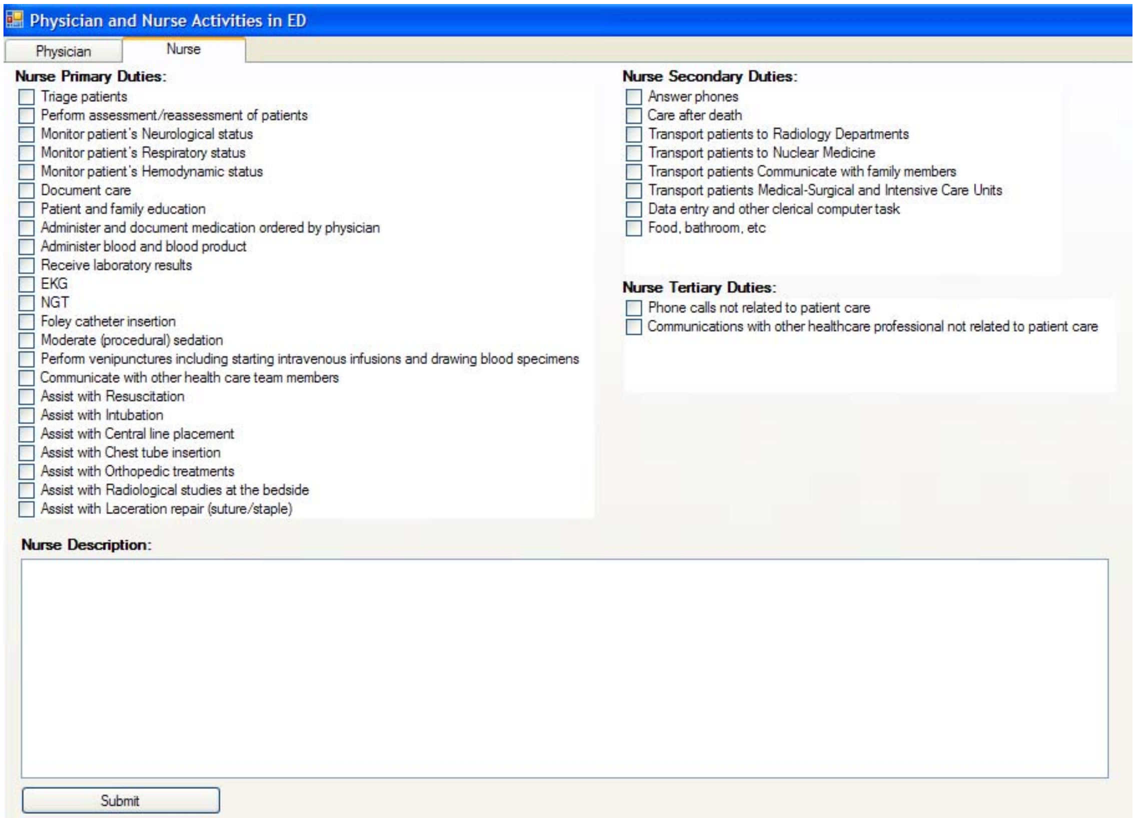

Figure 2. Observation tracking tool

The tool contains a list of commonly occurring activities for the Nurse and Physician. The activities chosen were based on an ontology developed by Jiajie Zhang based on his prior work on analyzing the workflow in emergency departments[2]. Observers may select an appropriate activity from the list provided and add detailed comments a description text box. The observations are then automatically dated and timed and stored in the output observation file. In this way time-stamped data is obtained for both qualitative and quantitative data sources. This makes synchronization of the two data streams possible.

Quantitative data is obtained using *active* RID tags to gather data. Active RID tags have an inbuilt power source, hence the name active. In addition to being portable, active tags use low levels of energy ensuring that they do not interfere with other devices, such as telephones and other network connections found in a health care setting. This is a vital requirement for the system. We chose off the shelf tags available from SNiF®. These are shown in figure 3. The tags record encounters with other tags (tag-tag encounter) and base stations (tag-base encounter). For each encounter or interaction, the tags record

(a) Identification number of the tag or base station detected

(b) Time and date of encounter, and

(c) The received signal strength indication (RSSI) value.

Figure 3. Active RID (SNiF®) tag and base station

The RSSI value provides proximity information. This value is inversely related to the distance between the interacting tags. Consequently, it can be used to measure approximate distances between tags and base stations involved in an interaction. The assessment of the temporally changing distance between entities (people and equipment alike), enables inferring the initiation of activities such as a resident leaving trauma, or a nurse documenting the case at the nurse's station. Such utilization of proximity information makes this a crucial metric for the functioning of the activity recognition system.

Base stations can be considered as fixed tags that provide tag location information. We place base stations at critical locations in the critical care environment. It was found that in a Trauma unit, the trauma bays, nurse's station and entry and exit points were some of the key locations. These locations will vary from site to site, depending on variations in the workflow. Placing base stations in these locations enables the determination of activities that occur in specific regions. Combining tag-tag and tag-base encounter information we can obtain an abstraction of interaction and communication activities between various entities in the clinical environment.

In order to develop our quantitative analysis system there is a need for training and validating the models. The procedures for data collection to train our quantitative system are as follows. Firstly, we identify certain movement activities, communication activities and interaction activities that are of interest. Subsequently, we place the RID tags on entities and collect data on the movements of entities when performing those activities. This data is then employed to train a model for automatic recognition of these activities in the future observations.

3.1.1 An illustrative example

Let us see an illustrative example of how some activities in the clinical environments can be captured by appropriate placement of tags and base stations (which are similar to tags in functionality but have a larger form factor. See figure 3). Consider the scenario representing patient arrival is depicted in Figure 4. Firstly, key members of the patient care team (resident, nurse and so on) gather by the bed of the patient. Following this, examination of the patient takes place. A resident may move to the telephone to consult or the nurse may move to the nurse's station to document details of the encounter. All these activities are linked to entities performing some type of movement in the environment.

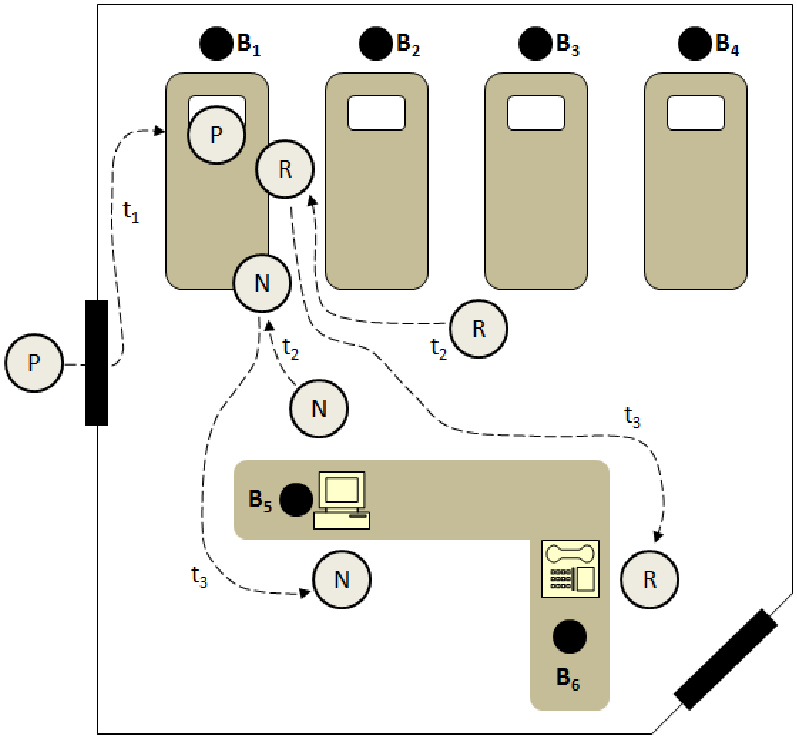

Figure 4. Scenario: Patient arrival at a trauma unit

Formally we can express this sequence of activities in terms of time as

(i) At time t_1: Patient arrives at the trauma unit and is sent to the trauma bay

(ii) At time t_2: The nurse and a resident check in on the patient

(iii) At time t_3: The resident seeks a phone consult while the nurse heads over to the station to continue with documentation.

In our diagram (Figure 4), 'P' refers to the patient; 'N' refers to the nurse and 'R' to the resident on call. The black solid dots denote location of base stations ($B_{1\text{-}6}$). Base stations were placed at various key locations; one at each trauma bay, one near the phone and the other near the computer. For these given sequence of events, the following are the trends we see in the data derived from the tags.

(i) At time t_2: Tags R and N get close to B_1.

(ii) At time t_3: Tag N is very close to B_5 and Tag R is very close to B_6.

With the initial setup phase we know that B_1 is trauma bay 1, we can assume that the patient is being managed by the nurse and resident at time t_2 and that the patient arrived at the unit sometime before t_2. Therefore, at time t_3, the system can probabilistically estimate that the nurse was documenting the patient report, and the resident was seeking a phone consult. While the scenario presented is a simplification of the total process, it provides a conceptual view of how we can track activities through tags. In reality, activity models generated can be more complex. The models would be required to handle variations in activities performed while classifying them accurately. A pattern recognition approach is required to handle such variations. The approach taken in this work to classify activities is discussed in the following section.

3.2 Activity modeling and recognition using Hidden Markov Modeling

Hidden Markov Modeling (HMM) is a probabilistic modeling tool that is usually employed for temporal sequence analysis and have been effectively used in movement analysis, gesture and speech recognition applications.[18,19] An HMM models a temporal sequence of events (called an observation sequence) in terms of a state machine, in which the current state of the model is probabilistically dependent on the previous states. A well-trained HMM activity model can detect the temporal activities that the HMM has been trained for.

As with any method, HMM based activity recognition has certain advantages and disadvantages. The key disadvantage of HMMs lies in the fact that the amount of data that is required to train an HMM is very large. Another issue with HMMs is that they require positive data to train with, i.e. in order to effectively train an HMM to recognize a class of activities, we require a carefully constructed training set that best describes the activity. However, these disadvantages are outweighed by a trained HMM's capability to handle variations in the final style of execution of an activity. Activities may be performed in a different manner in critical care environments and it is important that the model of activities accounts for these variations. By training the HMM system in a robust manner, it is possible to recognize the motion and some communication activities regardless of the deviations for our application. In addition, HMMs scale well as they can be trained to learn activities incrementally. New activities can be trained for without affecting models of previously learned activities. For these reasons, we chose HMMs for the development of activity models and activity recognition.

Activity recognition using HMMs is a 2 step process. It involves (i) *training*

HMMs for specific activity models and (ii) *testing* the HMMs for their recognition accuracy with annotated test samples. In order to develop robust activity HMMs, we first require data that describes the activity. This data is obtained from the RID tags. More specifically, the data utilized is the RSSI value of each tag-base encounter gathered during data collection. We collect this data for the activities of interest in multiple samples. We utilize half of the samples for training the HMMs and retain the rest for testing the developed models. A database of samples for each activity facilitates training the HMMs for each activity, thereby creating a library of HMM activity models for each activity. The training of HMM activity models is achieved using the Baum-Welch algorithm[20].

Once a library of HMMs is built with one HMM for each activity, the developed models can be tested. The testing of an activity sample proceeds by firstly, estimating the probability that the sample movement belongs to the library. This is achieved using the Forward-Backward[20] procedure for each of the HMM's in the library. The HMM that yields the highest probability for the test sequence is determined to be the type of activity that the movement sequence belongs to. The accuracy of recognition is measured as the ratio of the number of correctly identified test sequences to the total number of test sequences. In this manner, activity models are developed and tested for activity recognition. The recognized activities can then be visualized in 3D virtual environments.

3.3 Visualization of workflow in a virtual environment

The automated system for workflow analysis generates a series of activities that takes place in the clinical setting. Visualizing workflow in 3D enables researchers and clinicians alike to easily grasp the activities that make up the workflow. In addition to enable researchers review workflow in a novel way, the configurable VR visualizations can also be employed for educational purposes. For example, a resident would be able to go experience a trauma from the perspective of the attending or nurse. This kind of configurability would enable the cross-training of clinical teams. The visualizations can also be used to educate clinicians by illustrating cases of optimal workflow in relation to error-prone workflow.

In the domain of healthcare, virtual reality has been used to develop simulations for training of cognitive and psychomotor surgical skills and clinical decision making skills.[21-23] However, there is a lack of VR-based solutions for visualization of workflows and error scenarios even though such systems may have a major role to play in error prevention and mitigation. We can employ online VR environments such as Second Life® (http://secondlife.com/) and Active Worlds® (http://www.activeworlds.com/) for such visualizations. In this stage of the work, we have developed a standalone system that could be employed for such visualizations employing an open source gaming engine called Irrlicht (www.irrlicht.net).

A sample virtual trauma unit (see figure 5) was developed to mimic the trauma unit at Banner Good Samaritan Medical Center which is the site of development for the project. The virtual trauma room consists of four trauma pods or beds. The nurses' station faces the trauma pods. A computer and phone are key components that are included in the design of the nurses' station. Two exit doors are present in either side of the trauma room. These details are synchronous with the test and real-world set up. The current simulation contains 3 basic characters – the patient, resident and the nurse. The number and type of models to be utilized depend on the entities studied in the real-world. Models of the characters are built using modeling software (Maya and 3dMax; http://usa.autodesk.com/). Once the models are developed they can be controlled in the simulated world programmatically.

Figure 5. Virtual trauma unit for workflow visualization

In order to obtain VR simulations of the workflow, the system generates a list of activities making up the workflow. These activities are then manually fed into the visualization engine to create the simulations. Currently, this stage of visualization process is completed offline. VR simulations created in this manner present a simulated view of real-world events. This is valuable to clinicians and researchers in highlighting the main events in the workflow within the context of the clinical environment.

4 SYSTEM EVALUATION

The hypothesis being evaluated is that clinical activities involving movement patterns can be recognized by the HMM based activity recognition system. In addition, the evaluation seeks to quantify the accuracy of activity recognition (the ratio of the number of correctly identified activities to the total number of test activities). All observations and data gathering were performed after obtaining approval from Institutional Review Boards of involved institutions.

4.1 System evaluation setup

In order to test the HMM based activity recognition system, we simulated 15 Trauma activities (listed in Table 1) in a lab setting, (depicted in Figure 6) with 10 tags and 6 base stations. These activities were simulations of clinical activities. In order to simulate potential activities in a lab setting we observed commonly occurring movement tasks in the Trauma unit, an example being “physician moving to phone for a consult” (Activity A13). Figure 6 depicts the lab setup for testing and Table 1 summarizes the movement patterns and clinical descriptions of the 15 activities.

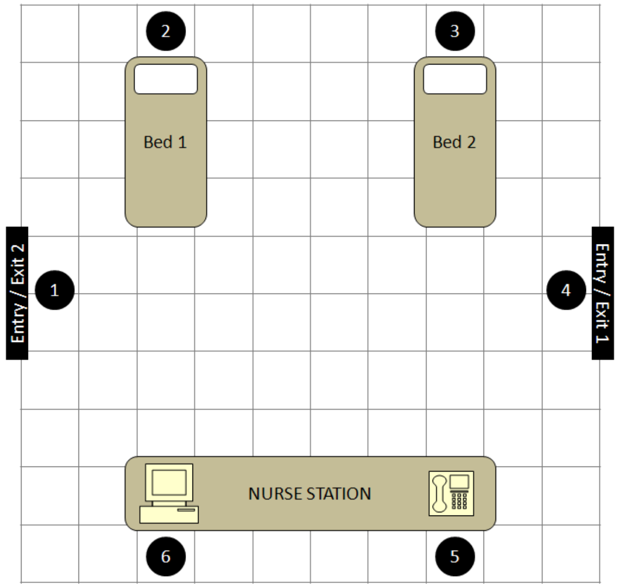

Figure 6. Test setup for simulated clinical activities

Activity	Movement	Clinical Description
A1	1-to-2	Paged physician/nurse tends to patient on bed 1
A2	2-to-3	Physician/Nurse moves to treat patient on bed 2
A3	3-to-4	Physician/Nurse leaves Trauma through entry/exit 1 after visiting patient on bed 2
A4	4-to-5	Physician/Nurse enters Trauma through entry/exit 1 and attends to the phone
A5	5-to-6	Physician/Nurse after attending to a phone call move to use the computer at the nurse station
A6	6-to-1	Physician/Nurse leaves Trauma through entry/exit 2
A7	1-to-4	Physician/Nurse enter and leave Trauma
A8	4-to-6	Physician/Nurse enter Trauma through entry/exit 1 and move to use the computer at the nurse station
A9	6-to-2	After using the computer physician/nurse move to treat patient on bed 1
A10	2-to-4	After visiting patient on bed 1, physician/nurse leaves Trauma through entry/exit 1

A11	5-to-1	After attending a phone call, physician/nurse leaves Trauma through entry/exit 2
A12	1-to-3	Paged physician/nurse attends to patient on bed 2
A13	3-to-5	After visiting patient on bed 2 physician seeks a phone consult
A14	5-to-2	After completing a phone call physician/nurse moves to treat patient on bed 1
A15	3-to-6	After treating patient on bed 2 physician/nurse move to use the computer at the nurse station

Table 1. Activity list and corresponding clinical descriptions

The setup for the testing involved the creation of a 20ft by 20 ft grid in a lab setting (grid lines depicted in Figure 6). Six base stations (depicted by black solid circles) we placed in predefined locations (Base 1 and 4 at Entry/Exit points 2 and 1 respectively; Bases 2 and 3 at Beds 1 and 2; Base 5 at the phone on nurse station; Base 6 at the computer on the nurse station). This is congruous with base station setup in the real-world scenario.

We gathered movement data for the 15 sample activities listed in Table 1. For each RID tag-base pair or tag-tag pair an encounter is recorded every 3 to 4.5 seconds. This data is captured in a time modulated manner i.e. encounter information is communicated by detecting differences in the time of the encounter rather than the frequency. This results in a sparse matrix when considering the entire tag-base station configuration. Figure 7 depicts a sample of the matrix generated. The encounters of a tag X with base stations A, B and C (gray filled boxes) are shown in a 60 second long timeline. We use linear interpolation to fill missing data in this sparse matrix. While this methodology provides an RSSI value for all base stations at all instances, it adds some noise to our system that may affect the overall activity recognition accuracy.

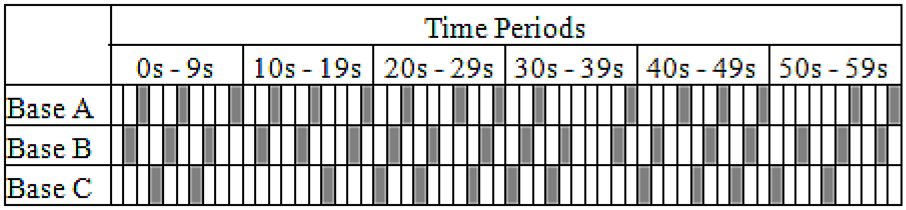

Figure 7. Sparse matrix of tag-base encounters (gray fill indicating an encounter record with some tag)

For each of these activities, we gathered 10 samples of data. Each sample involved a tagged entity (researcher) following the movement pattern prescribed for the activity. Each sample performed with 10 different tags, totaling 100 samples for each activity. This ensured sufficient randomization of activity movements, accounting for inter-tag variability as well. A total of 1500 samples (15 activities x 10 samples x 10 tags) were gathered for testing.

Out of the 100 samples gathered for each activity, 50 samples were used to train the HMM for activity recognition, and the other 50 were used as a testing set to evaluate the algorithms' accuracy.

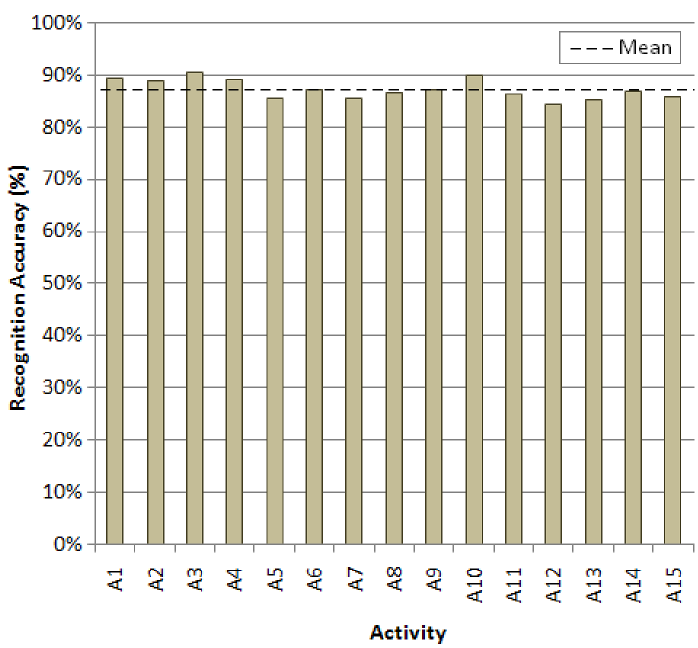

Figure 8. Hidden Markov Model (HMM) based activity recognition results

4.2 Results of HMM training

Figure 8 summarizes the recognition accuracy for the 15 motion patterns (A1 – A15) elucidated in Table 1. Recognition accuracy is the ratio of the number of activities correctly identified to the total number of activities used for testing. A mean recognition accuracy of 87.5% was obtained, with a maximum of 90.5% and minimum of 84.5%. The analysis of the incorrectly classified test samples revealed that misclassifications were a result of variations in the training set. As discussed previously, HMMs require to be trained on a well controlled sample that best represent the activity. Obtaining training data from real-world scenarios are abound to have variations that may compromise the quality of models generated. This is a limitation of utilizing HMM models with RSSI values alone for activity recognition. Additional sensors such as accelerometers could be utilized in conjunction with RID tags to improve the activity recognition rates. This is a part of our future work.

5 DISCUSSION

We are currently developing models for various activities in the workflow in a Trauma unit. The primary challenges to training HMMs for various activities lie in (i) developing a controlled set of samples that best represent the activity being modeled and (ii) the current limitations of RID tags. The linear interpolation adopted for dealing with missing data introduced further errors into the system. Our future work includes improving the recognition accuracy of the system by (i) increasing the sampling frequency of tags (ii) using alternate methods of interpolation to fill the sparse matrix and (iii) incorporating accelerometers with existing tags to refine data describing the movement. In addition, as the evaluation of the system was conducted in a controlled environment with a limited number of tags, further evaluation and testing with multiple tags in critical care units would be required to complete the validation of this system.

Initial data on the usability of the current application gathered during informal testing revealed positive usability and utility results. The experts pointed to the ability of VR simulations to focus on process and how this could be employed for several applications in the healthcare system. This is a major contribution of this work as to date there has been a lack of virtual worlds that are driven by real world data in the domain of healthcare.

6 CONCLUSION AND FUTURE WORK

The research and system described in this work lays the foundation for development of virtual worlds that are driven by real world data and real world needs. This would provide cognitive science researchers another dimension of data for clinical workflow analysis. Similar to a black box, the system provides a means to track all entities and a subset of their activities in the environment. In addition, the methods described can be applied to assess workflow not only in Trauma, but to any environment in which multiple team members are sufficiently mobile and geographically dispersed such that their movements might meaningfully reflect their activities.

Currently the system is capable of augmenting conventional data collection mechanisms to offer multidimensional activity information that allows observers to focus on cognitive details rather than simply annotating movement activities. Another use for this system is for the retrospective analysis of data. While existing workflow analysis systems support this type of analysis, the system described in the work can provide additional information that can be used to direct researchers to key events that need to be analyzed further. Visualization of workflow is another benefit of using this tool. In addition to enhancing our understanding of clinical workflow, such visualizations can also be used as an educational tool for training residents and nurse trainees in identifying errors and preventing the potential errors from leading to adverse events.

Future work will include developing more complex activity models and improving the HMM recognition rates. Additional data gathering for HMM modeling of activities and inclusion of audio recordings and accelerometers will enable the enrichment of information gathered. This will provide more information about the workflow and improve the capability of the system to capture and analyze workflow automatically.

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